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Study of the Possibility to Reuse Waste Plastic Bags as a Modifier for Asphalt Mixtures Properties (Binder Course Layer)

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Dedication

I proudly dedicate this thesis to my beloved father & mother for their unlimited support ..

With love & respect …

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Abstract

Use of recycled waste materials in road pavements is nowadays considered not only as a positive option in terms of sustainability, but also, as an attractive option in means of providing enhanced performance in service. This is especially true in the case of recycled plastics.

Thin plastic bags are mainly composed of low density Polyethylene (LDPE) and it's commonly used for packaging, protecting and many other applications. However disposal of waste plastic bags (WPB) in large quantities constitutes an environmental problem, as they considered non-biodegradable materials. Hence, there is a real need to find useful applications for these growing quantities of wastes. In this research, Waste Plastic Bags (WPB) as one form of polymers are used to investigate the potential prospects to enhance asphalt mixture properties. Study aims include studying the effect of adding different percentages of grinded WPB as an aggregate coat on the properties of asphalt mix comparing it with conventional mix properties besides identifying the optimum percent of WPB to be added in the hot mix asphalt.

WPB were introduced in the asphalt mixture in grinded form (2 - 4.75 mm). Marshal mix design procedure was used, first to determine the Optimum Bitumen Content (OBC) and then further to test the modified mixture properties. In total, (47) samples were prepared, 15 samples were used to determine the OBC and the remaining were used to investigate the effects adding different WPB percentages to asphalt mix. The OBC was 5.1 % by weight of asphalt mix. Seven proportions of WPB by weight of OBC were tested (6, 8, 10, 12, 14, 16 and 18%), besides testing of ordinary asphalt mix. Tests include the determination of stability, bulk density, flow and air voids.

Results indicated that WPB can be conveniently used as a modifier for asphalt mixes as a part of sustainable management of plastic waste as well as for improved performance of asphalt mix. WPB content of 9.0 % by weight of OBC is recommended as the optimum WPB content for the improvement of performance of asphalt mix. Asphalt mix modified with 9.0 % WPB by OBC weight has approximately 24 % higher stability value compared to the conventional asphalt mix. Asphalt mix modified with higher percentages of WPB exhibit lower bulk density, higher flow and higher air voids.

Study recommends local authorities to confirm using WPB in asphalt mix with the proposed percentage (9.0% by OBC weight) for improved performance of asphalt mix. Moreover, further studies are needed in various topics related to effective utilization and best incorporation techniques of waste materials in as

ملخص البحث

في الوقت الحاضر يعد استخدام النفايات المعاد تدويرها في رصفات الطرق ليس فقط خيارا إيجابيا من ناحية الاستدامة، ولكنه يعتبر أيضا خيارا جذابا من حيث تعزيز أداء هذه الرصفات، هذا ينطبق بشكل خاص في حالة البلاستيك المعاد تدويره .

الأكياس البلاستيكية الرقيقة تتكون أساسا من البولي إثيلين منخفض الكثافة (LDPE) وتستخدم عادة للتغليف والحفظ والعديد من الاستخدامات الأخرى. مع ذلك يعد التخلص من نفايات الأكياس البلاستيكية (WPB) بكميات كبيرة مشكلة بيئية لأنها تعتبر مواد غير قابلة لتحلل، ولذلك فإن هناك حاجة حقيقية لايجاد استخدامات مفيدة لهذه الكميات المتزايدة من النفايات. في هذا البحث، تم استخدام الأكياس البلاستيكية المستعملة باعتبارها جزء من البوليمرات للتحقق من احتمالات اسهامها في تحسين خصائص الخليط الأسفلتي (الطبقة الاسفلتية الرابطة). أهداف الدراسة تشمل تحديد تأثير إضافة نسب مختلفة من مخلفات الأكياس البلاستيكية المطحونة كغطاء لسطح الحصويات على خـ ائص الخليط الأسفلتي و مقارنتها مع خصائص الخليط الأسفلتي التقليدي إلى جانب تحديد نسبة البلاستيك المثلى لإضافتها للخليط الاسفلتي.

تم اضافة مخلفات الأكياس البلاستيكية للخليط الأسفلتي في شكل مطحون (2 - 4.75 مم). وقد استخدمت طريقة مارشال لتصميم الخلطة الاسفلتية لتحديد محتوى البيتومين الأمثل (OBC) وكذلك لاختبار خصائص الخليط الأسفلتي المضاف إليه البلاستيك، تم إعداد 47 عينة، وقد استخدمت 15 عينة لتحديد محتوى البيتومين الأمثل واستخدم العدد المتبقي من العينات لدراسة آثار اضافة النسب المختلفة من مخلفات الأكياس البلاستيكية الى الخليط الأسفلتي . نتائج فحص عينات مارشال بينت أن محتوى البيتومين الأمثل هو 5.1% من وزن الخليط الأسفلتي. تم اختبار تأثير اضافة ثمانية نسب من الأكياس البلاستيكية على خصائص الخليط الأسفلتي محـ وبة من وزن محتوى البيتومين الأمثل للخليط وهي (6, 8, 10, 12, 14, 16, 18%)، إلى جانب اختبار خصائص الخليط الأسفلتي العادي .الاختبارات شملت تحديد درجة الثبات والانسياب والكثافة الظاهرية ونسبة فراغات الهواء في الخليط الأسفلتي.

أشارت النتائج أنه يمكن استخدام مخلفات الأكياس البلاستيكية كمحسنات لخواص الخلطات الأسفلتية (الطبقة الأسفلتية الرابطة) كجزء من الإدارة المستدامة للمخلفات البلاستيكية وان إضافة الأكياس البلاستيكية بنسبة 9.0٪ من وزن OBC يعتبر النسبة المثلى لتحسين أداء الخلطة الأسفلتية حيث أن الخليط الأسفلتي المعدل بهذه النسبة يعطي 24٪ درجة ثبات أعلى مقارنة بالخليط الأسفلتي التقليدي. وأشارت النتائج أيضا أن اضافة الأكياس البلاستيكية بنسب أعلى يؤدي الى كثافة أقل، ودرجة انسياب ونسبة فراغات هواء أعلى للخليط الأسفلتي.

أوصت الدراسة السلطات المحلية باعتماد استخدام مخلفات الأكياس البلاستيكية بالنسبة المقترحة (9.0 % من وزن OBC) وذلك لتحسين أداء الخلطات الأسفلتية. وكذلك اجراء المزيد من الدراسات في المواضيع المتعلقة بالاستخدام الأمثل للمواد المختلفة للنفايات في الطبقات المختلفة للرصفة الأسفلتية.

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Abbreviations

WPB	Waste Plastic Bags
LDPE	Low-Density Polyethylene
HDPE	High-Density Polyethylene
HMA	Hot Mix Asphalt
OBC	Optimum Bitumen Content
ASTM	American Society of Testing and Materials
MSW	Municipal Solid Waste
ITS	Indirect Tensile Strength
d_{25}	Density of bitumen at 25°C
r_{bit}	Theoretical maximum density of asphalt mix
r_{A}	Density of Asphalt mix
$r_{\min}$	Density of aggregate in the blend
SSD	Saturated surface dry condition
VFB	Voids Filled Bitumen
VMA	Voids Mineral Aggregates
Vb	Bitumen Volume
Va	Air Voids

Chapter 1. Introduction

1.1 Background

As a result of rapid industrial growth in various fields together with population growth, an obvious increase in waste generation rates for various types of waste materials is observed. Disposal of that large amount of wastes especially non-decaying waste materials become a problem of great concern in developed as well as in developing countries. Recycling waste into useful products is considered to be one of the most sustainable solutions for this problem. So that, research into new and innovative uses of waste materials is extensively encouraged (Justo & Veeraragavan, 2002).

A wide variety of studies and research projects have been done to find useful applications of some of waste products in highways construction discussing wide range of aspects such as performance, suitability, environmental concerns, and feasibility of using each material. These studies try to find adequate combination of the need of safe and economic disposal of waste materials and the need of better and more cost-effective construction materials. Using recycled materials in road pavements is nowadays considered not only as a positive option in terms of sustainability, but also, as an attractive option in means of providing enhanced performance in service (Justo & Veeraragavan, 2002).

It's proven that the addition of certain polymer to asphalt binder can improve the performance of road pavement. The addition of polymers typically exhibit greater resistance to rutting and thermal cracking. Besides, it decreased fatigue damage, stripping and improved temperature susceptibility. Polyethylene is extensively used plastic material, and it has been found to be one of the most effective polymer additives (Awwad & Shabeeb, 2007; Kalantar *et al.*, 2010).

Thin plastic bags are mainly composed of Low Density Polyethylene (LDPE) and it's widely used for packaging. However, disposal of waste plastic bags (WPB) in large quantities has been a problem as it's not a biodegradable material. Several studies have been made on the possible use of waste plastic bags and plastics in general in asphalt mix. Depending upon their chemical composition and physical state, they have been employed as binder modifiers or as aggregates coat as well as they can be used as elements which partially substitute portion of aggregates in asphalt mix. Results were encouraging and exhibit an improvement in performance of the modified asphalt mixes (Justo & Veeraragavan, 2002; Giriftinoglu, 2007).

1.2 Problem statement

Plastic is everywhere in today's lifestyle, it has numerous applications in various sectors such as packaging, protecting, agriculture, construction and even disposing of all kinds of consumer goods. Plastic constitutes significant part of municipal waste in Gaza strip. It's in the range of (10-13%) by weight of municipal waste (Abdalqader, 2011). Unfortunately, plastic is non-biodegradable material which will remain in the environment for hundreds of years leading to waste disposal crisis as well as various environmental concerns. Hence there is a real need for innovative and sustainable approaches to use these growing quantities of wastes. One solution to this crisis is recycling waste into useful products (Swami *et al.*, 2012). In other side, the increase in traffic loading repetitions in combination with an insufficient degree of maintenance caused an accelerated deterioration of the road network (Awwad & Shabeeb, 2007). Scientists and engineers are constantly searching on different methods to improve the performance of asphalt pavements. This study was conducted to investigate the possible use of waste plastic bags (WPB) as a modifier of hot-mix asphalt and to review the feasibility of incorporating WPB to improve the performance of asphalt mix.

1.3 Aim and Objectives

a. Aim

The aim of this research is to investigate the possibility to reuse Waste Plastic Bags (WPB) as an aggregate coat to modify asphalt mix properties (binder course layer).

b. Objectives

- Study the effect of adding different percentages of WPB as an aggregate cover on the properties of asphalt mix comparing it with conventional mix properties.
- Identify the optimum percent of WPB to be added in the hot mix asphalt.

1.4 Importance of the study

- Finding useful application for WPB as a part of solution for environmental problems resulting from disposal.
- Study the ability of using WPB as low price asphalt additive in order to

improve performance of asphalt roads as well as to extend their service life.

1.5 Methodology

To achieve study goals, implementation would include the following:

a) Literature review of previous studies which include revision of books, scientific papers and reports in the field of recycled polymer modifiers of asphalt mix.
b) Site visits and investigations of the recycled plastic processing plants to get more information and collect samples.
c) Deep study of asphalt mix design and asphalt production technology.
d) Identifying Optimum Bitumen Content (OBC) using Marshal Mix design procedure. Five percentages of bitumen have been examined to determine the best percentage of bitumen for the aggregates used, which include 4, 4.5, 5, 5.5 and 6% by weight of the mix.
e) Identifying the effects of adding different percentages of WPB modifier on the asphalt mix properties comparing it with conventional mix in terms of bulk density, Marshal stability, flow and air voids. Intended percentages are from 6% to 18 % by weight of OBC.
f) Discussion of testing results.
g) Drawing conclusions and recommendations.

§ **Number of samples**

- Marshal test design procedure: 5 percentages x 3 samples for each percentage = 15 samples.
- Conventional mix tests (0% WPB) = 4 samples.
- WPB addition tests: 7 percentages of WPB (from 6 - 18 % with 2% incremental by weight of OBC) x 4 samples for each percentage = 28 sample.
- Total number of samples required= approximately 47 samples.

1.6 Study limitations

The results of this study depended on set of limitations and criteria that were taken into account during the experimental work. These limitations include:

a) Only one type of plastics was studied as a modifier of asphalt mixtures properties which is waste thin plastic bags.
b) WPB are added as an aggregate coat in the asphalt mix.
c) Percentages of WPB are utilized in asphalt mix within the range of 6 – 18% with 2% incremental by OBC weight.

1.7 Thesis structure

Thesis includes five chapters and six appendices. A brief description of the chapters' contents is presented below:

Chapter 1: Introduction

This chapter is a briefly introduction, which highlights the concept of research. In addition, statement of problem, aim, objectives and methodology of research are described.

Chapter 2: Literature review

Brief introduction related to hot mix asphalt, polymers, plastic waste and its utilization in asphalt mix is included in this chapter. Moreover, previous researches relevant to polymer modified asphalt mixes including recycled plastics are reviewed.

Chapter (3) Materials and study program

This chapter handles two topics first is the preliminary evaluation of used materials properties such as aggregates, bitumen and waste plastics. Second is the description of experimental work which has been done to achieve study aims.

Chapter (4) Results and data analysis

The achieved results of laboratory work are illustrated in this chapter through three stages. First stage handles the results of blending aggregates to obtain asphalt binder course gradation curve. Second stage, Marshal Test results are analyzed in order to obtain the optimum bitumen content (OBC). The following step discusses the effect of adding different percentages of WPB on asphalt mix properties; finally the optimum WPB modifier content is obtained.

Chapter (5) Conclusion and recommendations

Conclusions derived from experimental results are presented. Moreover, the recommendations for the present study and other further studies are also provided in this chapter.

Chapter 2. Literature Review

2.1 Introduction

Asphalt pavement is a composite material consisting of mineral aggregates, asphalt binder and air voids. The load-carrying behavior and resulting failure of such material depends on many mechanisms that are strongly related to the local load transfer between aggregate particles (Sadd *et al.*, 2004).

The increase in traffic loading repetitions in combination with an insufficient degree of maintenance and difficulties in supplying high quality materials due the siege imposed on Gaza strip has caused an accelerated and continuous deterioration of the road network. To alleviate this process, several ways may be effective, e.g., securing funds for maintenance, improved roadway design, better control of materials quality and the use of more effective construction methods (Awwad & Shabeeb, 2007).

Asphalt pavement performance is affected by several factors, e.g., the properties of the components (binder, aggregate and additive) and the proportion of these components in the mix. The performance of asphalt mixtures can be improved with the utilization of various types of additives, these additives include: polymers, latex, fibers and many chemical additives (Taih, 2011; Awwad & Shabeeb, 2007).

It’s proven that the addition of certain polymer additive to asphalt mix can improve the performance of road pavement. The addition of polymers typically exhibit improved durability, greater resistance to permanent deformation in the form of rutting and thermal cracking. Besides, it increases stiffness and decreased fatigue damage. Waste plastic bags (WPB) which is mainly composed of Low Density Polyethylene (LDPE) has been found to be one of the most effective polymer additives which would enhance the life of the road pavement and also solve many environmental problems (Al-Hadidy & Tan, 2011; Jain *et al.*, 2011; Kalantar *et al.*, 2010).

2.2 Hot Mix Asphalt

Hot-Mix Asphalt (HMA) is the most widely used paving material around the world. It's known by many different names: HMA, asphaltic concrete, plant mix, bituminous mix, bituminous concrete, and many others. It is a combination of two primary ingredients aggregates and asphalt binder. Aggregates include both coarse and fine materials, typically a combination of different size rock and sand. The aggregates total approximately 95% of the total mixture by weight. They are mixed with approximately 5% asphalt binder to produce HMA. By volume, a typical HMA mixture is about 85%

aggregate, 10% asphalt binder, and 5% air voids. Additives are added in small amounts to many HMA mixtures to enhance their performance or workability. Because asphalt concrete pavement is much more flexible than Portland cement concrete pavement, asphalt concrete pavements are sometimes called flexible pavements (Transportation research board committee, 2011).

Asphalt concrete pavements are engineered structures composed of a group of layers of specific materials that is positioned on the in-situ soil (Sub Grade). Figure (2.1) shows a vertical section of typical asphalt concrete pavement structure.

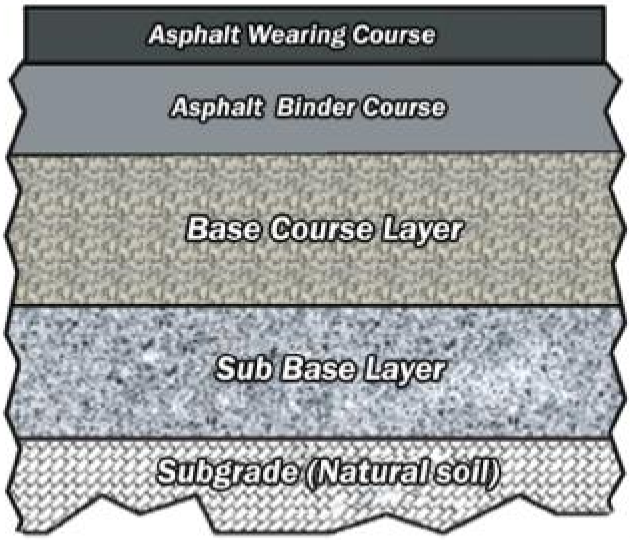

Figure (2.1): *Vertical section of asphalt concrete pavement structure*

2.2.1 Basic materials in hot mix asphalt

2.2.1.1 Aggregates

Aggregates (or mineral aggregates) are hard, inert materials such as sand, gravel, crushed rock, slag, or rock dust. Properly selected and graded aggregates are mixed with the asphalt binder to form HMA pavements. Aggregates are the principal load-supporting components of HMA pavement.

Because about 95% of the weight of dense-graded HMA is made up of aggregates, HMA pavement performance is greatly influenced by the characteristics of the aggregates. Aggregates in HMA can be divided into three types according to their size: coarse aggregates, fine aggregates, and mineral filler. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve. Fine aggregates are those that pass through the 2.36-mm sieve and are retained on the 0.075-mm sieve. Mineral filler is defined as that portion of the aggregate passing the 0.075-mm sieve. Mineral filler material - also referred to as mineral dust or rock dust - consists of very fine, inert mineral with the consistency of flour, which is added to the hot mix asphalt to improve the density and strength of the mixture. It shall be incorporated as part of the combined aggregate gradation (Chen, 2009; Transportation research board committee, 2011).

2.2.1.2 Asphalt binder (bitumen)

Asphalt binder (bitumen) which holds aggregates together in HMA is thick, heavy residue remaining after refining crude oil. Asphalt binder consists mostly of carbon and hydrogen, with small amounts of oxygen, sulfur, and several metals. The physical properties of asphalt binder vary considerably with temperature. At high temperatures, asphalt binder is a fluid with a low consistency similar to that of oil. At room temperature most asphalt binders will have the consistency of soft rubber. At subzero temperatures, asphalt binder can become very brittle. Many asphalt binders contain small percentages of polymer to improve their physical properties; these materials are called polymer modified binders. Most of asphalt binder specification was designed to control changes in consistency with temperature (Transportation research board committee, 2011).

2.2.2 Desirable properties of asphalt mixes

Mix design seeks to achieve a set of properties in the final HMA product. These properties are related to some or all variables which include asphalt binder content, asphalt binder characteristics, degree of compaction and aggregate characteristics such as gradation, texture, shape and chemical composition. Some of the desirable properties of asphalt mixes are listed below with brief description of each (Wayne *et al.,* 2006):

a) Resistance to permanent deformation: The mix should not distort or be displaced when subjected to traffic loads especially at high temperatures and long times of loading.
b) Durability: The mix must be capable to resist weathering effects (both air and water) and abrasive action of traffic. Asphalt mix should contain sufficient asphalt cement to ensure an adequate film thickness around the aggregate particles.
c) Fatigue resistance: The mix should not crack when subjected to repeated loads over a period of time.
d) Skid resistance. The mix must have sufficient resistance to skidding, particularly

under wet weather conditions. Aggregate properties such as texture, shape, size, are all factors related to skid resistance.

e) Workability: The mix must be capable of being placed and compacted to specific density with reasonable effort.

f) Moisture damage resistance: HMA should not degrade substantially from moisture penetration into the mix.

g) Low noise and good drainage properties: This property is important for the wearing layer of the pavement structure.

h) Resistance to low temperature cracking. This mix property is important in cold regions.

2.2.3 Gradation specifications for asphalt binder course

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In hot-mix asphalt, gradation helps to determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, and resistance to moisture damage. Gradation is usually measured by a sieve analysis. Table (2.1) and Figure (2.2) indicates international gradation limits for the asphalt binder course (ASTM D3515).

Table (2.1): *Gradation of Asphalt Binder Course (ASTM D5315)*

Sieve No.	Sieve size (mm)	Percentage by Weight Passing	
		Min	Max
1"	**25.00**	100	100
3/4"	**19.00**	90	100
1/2"	**12.50**	67	85
3/8"	**9.50**	56	80
#4	**4.75**	35	65
#10	**2.00**	23	49
#50	**0.30**	5	19
#100	**0.15**	3	14
#200	**0.075**	2	8

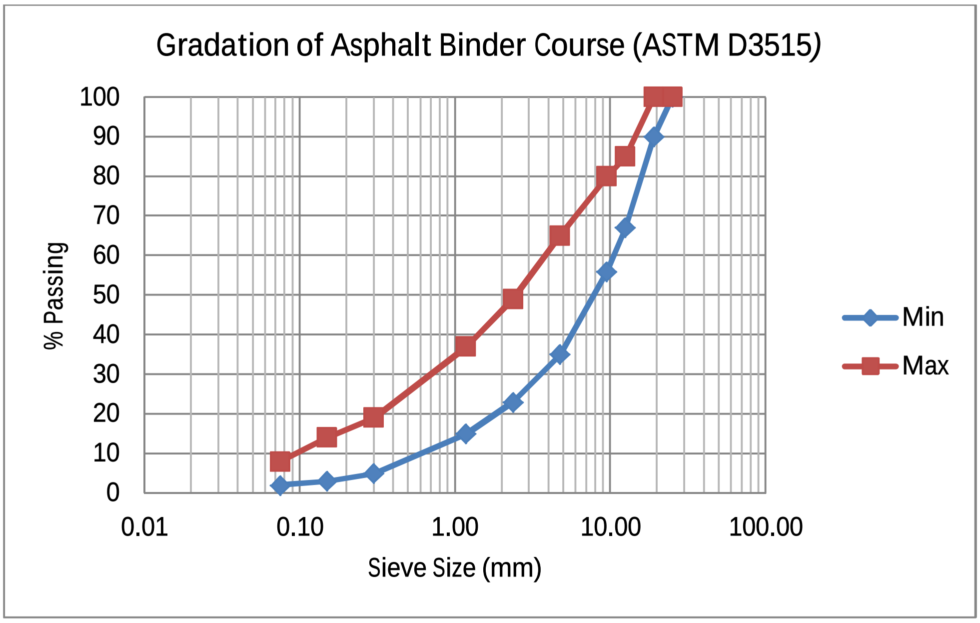

Figure (2.2): *Gradation of Asphalt Binder Course (ASTM D3515)*

2.2.4 Mechanical properties specifications for asphalt binder course

Two specifications for the mechanical properties of asphalt binder course are reviewed. First is the Municipality of Gaza (MOG) local projects specification. Second is the Asphalt Institute specification AS (MS-2). Table (2.2) summarizes these specifications.

Table (2.2): *Mechanical properties specifications for asphalt binder course*

Property	Local Spec. (MOG, 1998)		International Spec. (Asphalt Institute, 1997)	
	Min.	Max.	Min.	Max.
Stability (kg)	900	*	817	*
Flow (mm)	2	4	2	3.5
Void in Mineral aggregate (VMA)%	13.5	*	13	*
Air voids (Va)%	3	7	3	5
Bulk density (gm/cm^3)	2.3	*	2.3	*

2.3 Polymer modified asphalt mix

2.3.1 Introduction

In order to improve the performance of asphalt pavements, many polymeric substances have been incorporated in asphalt mix as additives in many forms. Polymer modification of bitumen and asphalt mix offers several benefits. These include enhanced fatigue resistance, improved thermal cracking resistance, decrease in temperature susceptibility, and improve rutting resistance (Kalantar *et al.*, 2010).

Polymers are mainly incorporated in asphalt mix as binder (bitumen) modifier. They also can be added to form an aggregates coating material. Moreover, they can be utilized as partial substitute of certain size of aggregates in asphalt mix. Properties of modified asphalt mix depend on various factors such as polymer characteristics, mixing conditions and compatibility of polymer with asphalt mix contents.

Polymers have many types and classifications. Plastics are one the most widely used polymers nowadays. Considerable research has been carried out to determine the suitability of plastic wastes to be utilized in asphalt mix. Plastic wastes utilization in asphalt mix will be discussed and previous studies in this field will be reviewed later in this chapter.

2.3.2 Polymers structure and classification

'Polymer' is a derived word meaning "of many parts". Polymer is simply refers to very large molecules made by chemically reacting many small molecules (monomers) to produce long chains. Chemical structure, molecular weight and sequence of monomers of specific polymer determine its physical properties (Becker *et al.*, 2001).

Polymers can be classified as elastomers, or plastomers. Elastomers (rubbers) refer to elastomeric which prescribe the ability of a material to return to its original shape when a load is removed. Elastomers typically include copolymers of styrene and butadiene. They also include natural and synthetic rubbers (e.g. Crumb Rubber Modifier CRM) (Hansen *et al.*, 200l; Awwad & Shabeeb, 2007).

Unlike Elastomers, Plastomers attain high strength and resistance to deformation at rapid rate, but are brittle. Plastomers include ethylene vinyl acetate (EVA), polyethylene, and various compounds based on polypropylene.

Elastomeric and Plastomeric polymers are more classified as either thermoset or thermoplastic. When initially heated, thermoset polymers develop a complex structure, which is retained upon cooling, but which cannot be reversed when reheated. In contrast, thermoplastic polymers also develop a well-defined, linked structure when cooled, but the resultant structure can be reversed with reheating (King & Johnston, 2012).

Table (2.3) presents a summary polymer types, classified according to their deformational and thermal properties.

2.4 Plastic polymers

Plastics are mainly organic polymers of high molecular mass. The raw materials for plastics production are natural products such as cellulose, coal, natural gas, salt and crude oil. Different plastics have different polymer chain structures which determine many of their physical characteristics. The vast majority of these polymers are based on chains of carbon atoms alone or with oxygen, sulfur, or nitrogen as well (Giriftinoglu, 2007).

2.4.1 Types of plastics

The Society of the Plastics Industry (SPI) established a special numbered coding system in 1988 to allow consumers and recyclers to properly identify the type of resin that was used in manufacturing a product. Manufacturers follow a coding system and place an SPI code, or number, on each plastic product, which is usually molded into the bottom. Table (2.4) illustrates the most common types of plastics used, their applications and SPI code (Giriftinoglu, 2007).

Table (2.3): *Types and Classification of Polymers (King & Johnston, 2012)*

Polymer Type	Examples	Deformational Classification	Thermal Classification
Natural Rubber (Homopolymers)	Natural Rubber (NR), Polyisoprene, Isoprene, Natural Rubber Latex (NRL)	Elastomer	Thermoset
Synthetic Latex / Rubber (Random Copolymers)	Styrene-Butadiene (SBR)	Elastomer	Thermoset
	Polychloroprene Latex (Neoprene)	Elastomer	Thermoset
	Polybutadiene (PB, BR)	Elastomer	Thermoset
Reclaimed Rubber	Crumb Rubber Modifiers	Elastomer	Thermoset
Block Copolymers	Styrene-Butadiene-Styrene (SBS)	Elastomer	Thermoplastic
	Styrene-Isoprene-Styrene (SIS)	Elastomer	Thermoplastic
	Styrene-Butadiene (SB) Diblock	Elastomer	Thermoplastic
	Acrylonitrile-Butadiene-Styrene (ABS)	Elastomer	Thermoplastic
	Reactive-Ethylene-Terpolymers (RET)	Elastomer	Thermoplastic
Plastics	Low / High Density Polyethylene (LDPE / HDPE), Other Polyolefins.	Plastomer	Thermoplastic
	Ethylene Acrylate Copolymer	Plastomer	Thermoplastic
	Ethyl-Vinyl-Acetate (EVA)	Plastomer	Thermoplastic
	Ethyl-Methacrylate	Plastomer	Thermoplastic
	Polyvinyl Chloride (PVC)	Plastomer / Elastomer	Thermoplastic
	Ethylene-Propylene-Diene-Monomer (EPDM)	Plastomer	Thermoplastic
	Acrylates, Ethyl-Methacrylate (EMA), Ethyl-Butyl-Acrylate (EBA)	Plastomer	Thermoplastic
Combinations	Blends of Above	Varies	Varies

Table (2.4): *Types of plastics, their applications and SPI code (Giriftinoglu, 2007)*

Plastic type	Abbreviation	Examples of applications	SPI
Polyethylene Terephthalate	**PET**	Soft drink and water bottles.	1 PET
High Density Polyethylene	**HDPE**	Cleaners and shampoo bottles, molded plastic cases.	2 HDPE
Polyvinyl Chloride	**PVC or V**	Pipes, fittings, credit cards, toys, electrical fittings, pens; medical disposables; etc	3 V
Low Density Polyethylene	**LDPE**	Grocery bags and packaging films.	4 LDPE
Polypropylene	**PP**	Bottle caps and closures, diapers, microwaveable meal trays, medicine and syrup bottles, also produced as fibers and filaments for carpets.	5 PP
Polystyrene	**P S**	Styrofoam, Take-away food containers, egg cartons, disposable cups, plastic cutlery, CD and cassette boxes.	6 PS
Other types of plastics		Any other plastics that do not fall into any of the above categories - for example polycarbonate which is Compact discs, eyeglasses, riot shields, security windows.	7 OTHER

2.4.2 Plastics waste problem

As a result of rapid industrial growth in various fields together with population growth, an obvious increase in waste generation rates for various types of waste materials is observed. Many of the wastes produced today are non-biodegradable such as blast furnace slag, fly ash, steel slag, scrap tyres, plastics, etc. that will remain in the environment for hundreds of years leading to waste disposal crisis as well as various environmental concerns.

Plastics industry have many major developments in the last two decades resulted from the increased utilization of plastics in various sectors e.g. Packaging, protecting, buildings, agriculture, high-tech, and water management etc. Plastics now are everywhere and have innumerable uses. Use of this non-biodegradable product is growing rapidly, in the same time plastic wastes is also growing day by day and the problem is how to deal with these wastes (Jain *et al.*, 2011).

One of the most common used plastics is the thin plastic bags which used usually for packaging. However the disposal of the waste plastic bags in large quantities constitutes a real environmental problem, due to their chemical inertness. Hence, there is a real need to find useful applications for these growing quantities of wastes. Recycling waste into useful products is considered one of the most sustainable solutions to this crisis so that research into new and innovative uses of waste materials is continually advancing (Justo & Veeraragavan, 2002).

2.4.3 Plastic waste in Gaza strip

Gaza strip produces a huge amount of solid waste daily, it's about (1420 ton/day) of solid waste. Plastic waste constitutes significant part of municipal solid waste (MSW), which generally comprises nearly 12% by weight of MSW (172 tons/day). The category "plastic" included all grades of plastic bags, bottles, packaging, and all grades of hard and soft plastics from toys, appliances, and many other sources. Figure (2.3) illustrates MSW composition in Gaza Strip (Abdalqader, 2011).

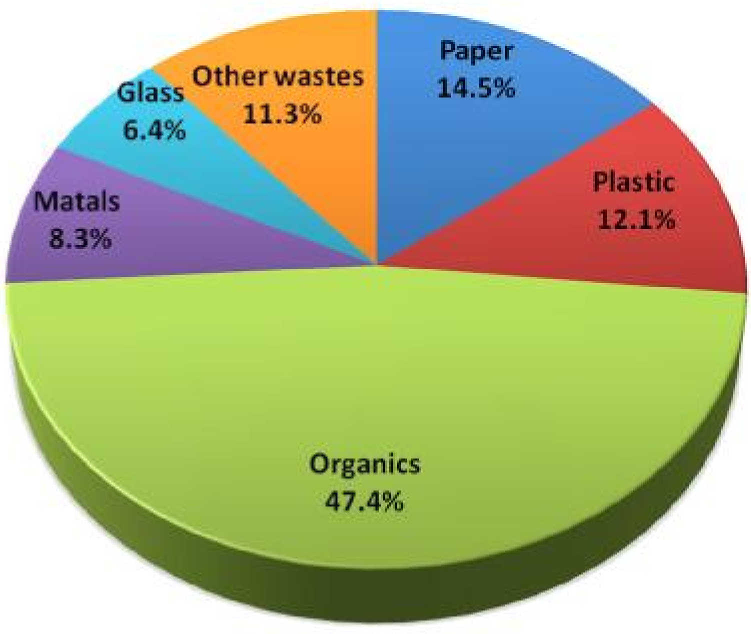

Figure (2.3): *Municipal solid waste composition in Gaza strip (Abdalqader, 2011)*

2.4.4 Plastic Wastes utilization in asphalt mixtures

Waste plastic as one sort of plastomer polymers can be utilized in asphalt concrete mix through three different processes namely dry process, wet process and the third process includes using waste plastic as partial substitute of certain size of aggregates.

Dry process include incorporating plastic polymer which is blended with hot aggregates to form an aggregate coating layer usually by plastic milting over hot aggregate surface before adding bitumen. This coating layer would enhance bonding and engineering properties of aggregates leading to improvement in durability of asphalt mixtures depending on plastic characteristics and mixing conditions. Dry process is applicable only for plastic polymers (Awwad & Shabeeb, 2007; Gawande *et al*, 2012).

Wet process involves simultaneous blending of bitumen and waste plastic. Polymer modification of bitumen including plastic polymer is a common method to improve the quality of bitumen by modifying its rheological properties through blending with synthetic polymers (Gawande *et al*, 2012). Bitumen modification through adding polymer offers many enhancements for asphalt mixtures that may include improvements in rutting resistance, thermal cracking, fatigue damage, stripping and temperature susceptibility. These improvements led polymer modified bitumen to be a substitute for ordinary bitumen in many paving and maintenance applications. Properties of modified bitumen depend on various factors such as polymer - bitumen characteristics, mixing conditions and compatibility of polymer with bitumen. Polymers are incorporated in bitumen with two methods, first is the addition of latex polymer to bitumen which offer relatively easy dispersing of polymer. Second is the addition of solid polymers to bitumen which normally requires a high shear mixer to obtain uniformly dispersed mix (Becker *et al.*, 2001).

Another method to incorporate plastics in asphalt mixture is to replace a portion of mineral aggregates of an equal size of polymer which is mainly used to incorporate waste plastic and consumes a greater proportion of plastic in asphalt mix.

2.5 Laboratory studies related of plastics utilization in asphalt mixes

Several investigations have been carried out on incorporating polymers to improve performance of asphalt mixtures. Recycled plastics as one sort of polymers can replace a portion of aggregates or serve as a binder modifier moreover it can be used as an aggregates coating material.

2.5.1 Using plastics for binder modification

Justo and Veeraragavan (2002) studied the possibility of using processed plastic bags as an additive in asphalt concrete mix, the processed plastic was used as an additive with heated bitumen in different proportions (ranging from zero to 12 % by weight of bitumen) and mixed well to obtain the modified bitumen. Laboratory investigations have given highly encouraging results for the use of modified bitumen. Results show that the addition of processed plastic, about 8.0 % by weight of bitumen, helps in substantially improving the stability or strength, fatigue life and other desirable properties of asphalt concrete mix, even under adverse water-logging conditions. Therefore the life of the pavement surfacing course using the modified bitumen is also expected to increase substantially in comparison to the use of ordinary bitumen. Besides, the addition of 8.0 % processed plastic by weight of bitumen for the preparation of modified bitumen results in a saving of 0.4 % bitumen by weight of the mix that would contribute in reducing the overall cost of asphalt mix.

According to **Chen (2009)** Re-cycled Polythylene Terephthalate (PET) may be useful in asphalt pavements, resulting in reduced permanent deformation in the form of rutting of the pavement surfacing. PET is widely used in water and soft drink bottles and it's commonly recycled. Chen's study aim was to evaluate the rut resistance of PET as polymer additives to asphalt mix. Study includes determining the maximum percentage of PET as bitumen modifier and comparison the PET modified asphalt mix with conventional mix in term of rut resistance. The tests include the determination of penetration index, Marshall Test and three wheel immersion tracking test which utilized to evaluate rut resistance. The maximum plastic content was 7.5% and the optimum bitumen content (OBC) for ordinary mix was 5.3% while the OBC for PET modified mix was 5.2%. Study concluded that PET modified asphalt binders provide better resistance against permanent deformations due to the binding property of plastic in PET modified asphalt mix which presented in more durability and lower rut depth compared to conventional mix.

Kalantar *et al* (2010) investigated the possibility of using waste PET as polymer additives for binder in asphalt mix. Waste PET is powdered and mixed in proportions 2, 4, 6 , 8 and 10 % (by the weight of OBC) with bitumen at temperature 150 C. PET modified binder resulted in higher resistance to permanent deformation and higher resistance to rutting due to their higher softening point when compared to conventional binders. Decrease in consistency and increase in the resistance to flow and temperature changes also appears in PET modified binder.

2.5.2 Using plastics as an aggregate coat

Awwad and Shabeeb (2007) investigated using polyethylene as one sort of polymers to enhance asphalt mixture properties, two types of polymers in two states were added to coat mix aggregates (Grinded and not grinded Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE)). Optimum Bitumen Content (OBC) is first determined using Marshal mix design procedure then seven proportions of polyethylene of each type and state by weight of OBC were selected to be tested (6, 8, 10, 12, 14, 16 and 18%). The tests include the determination of bulk density, stability and flow. Results indicated that 12% of grinded HDPE polyethylene modifier provides better engineering properties. It is found to increase the stability, reduce the density and slightly increase the air voids.

Jain *et al.* (2011) reported that the incorporation of waste polymeric packaging material (WPPM) in the bituminous mixes enhance pavement performance as well as protect the environment. Study includes reusing milk bags and other HDPE based carry bags as additives in bituminous mixes. Results revealed that the optimum dose of WPPM is 0.3% to 0.4% by weight of asphalt mix. Higher dose lead to undesirably higher stiffness of mix. It’s found that using of WPPM in bituminous mixes substantially improving performance properties which include reduction in rutting and deformation values. Authors encourage using of WPPM in road construction as a sustainable option for disposal of non-degradable plastic waste.

Sabina *et al*. (2009) compared properties of bituminous mixes containing plastic/polymer (PP) (8% and 15% by weight of bitumen) with conventional bituminous mixes. Waste PP modifier was used in a shredded form (Particle size, diam 2-3 mm), graded aggregates were heated at 150-160C in oven and waste PP modifier was added into hot aggregates before mixing OBC. Marshall Specimens for conventional and modified mixes were tested. Results show that marshal stability of modified mixes was 1.21 and 1.18 times higher than conventional mixes for modifier proportions 8 and 15% respectively. ITS and rutting resistance were also improved in modified mixes. Indirect Tensile Strength (ITS) for conventional mix was 6.42 kg/cm^2 while these where 10.7 and 8.2 kg/cm2 for modified mixes 8 and 15% respectively, rutting for conventional mix was (7 mm) while these where 2.7mm and 3.7mm for modified mixes 8 and 15%

respectively). Thus waste PP modified bituminous mixes are expected to be more durable and have an improved performance in field conditions.

2.5.3 Using plastics to replace aggregates

Zoorob and Suparma (2000) discussed using recycled plastics mainly composed of LDPE in pellet form to replace (by volume) a portion of the mineral aggregates of an equal size (2.36–5.0 mm) producing new mix named (Plastiphalt). Results indicated that 30% aggregate replacement by volume with recycled plastic pellets reduce bulk density by 16% and show much higher Marshal stability, approximately 2.5 times that of control mix. Recorded flow values were also higher indicating that Plastiphalt mixes are both stronger and more elastic. Besides, the ITS value was found to be higher in Plastiphalt mix. Overall, the mechanical properties of aged recycled Plastiphalt mixes are superior to those of control mixes composed of mineral aggregates.

2.5.4 Conclusion

After reviewing the previous studies related to utilization of plastics and plastics wastes in the asphalt mix as a modifier, it’s clear that there are different forms for addition of plastics to asphalt mix which can improve asphalt mix properties. Properties of modified asphalt mix are related to many aspects such as plastic type, utilization form and percentage of added plastic. In this study one type of plastics which is thin waste plastic bags will be utilized in the asphalt mix as an aggregate coat. The effect of adding WPB in the range 6-18% with 2% incremental by the weight of OBC will be studied. Locally available bitumen and aggregates will be used in this study.

Chapter 3. Materials and Study Program

3.1 Introduction

The main objective of this study is to evaluate the properties of hot mix asphalt modified with waste plastic bags. Process and procedures on how this study is carried out will be explained in detail.

This chapter deals with two topics. First, is to evaluate used materials properties such as aggregates, bitumen and waste plastics. Second, is to describe how experimental work has been done to achieve study objectives.

3.2 Laboratory Test Procedure

This study is based on laboratory testing as the main procedure to achieve study goals. All the testing is conducted using equipment and devices available in the laboratories of Islamic university of Gaza.

Laboratory tests are divided into several stages, which begin with evaluation of the properties of used materials as aggregates, bitumen, and plastics. Sieve analysis is carried out for each aggregate type to obtain the grading of aggregate sizes followed by aggregates blending to obtain binder course gradation curve used to prepare asphalt mix. After that, Asphalt mixes with different bitumen contents are prepared and marshal test is conducted to obtain optimum bitumen content. The value of the optimum bitumen is used to prepare asphalt mixes modified with various percentages of waste plastic bags. Marshal Test will be utilized to evaluate the properties of these modified mixes. Finally, laboratory tests results are obtained and analyzed. Figure (3.1) shows the flow chart of laboratory testing procedure.

3.1 Materials Selection

Materials needed for this study are the constituents of hot mix asphalt and Waste Plastic bags, table (3.1) present main and local sources of these materials. Figures (3.2) and (3.3) show sources of aggregates and waste plastic bags.

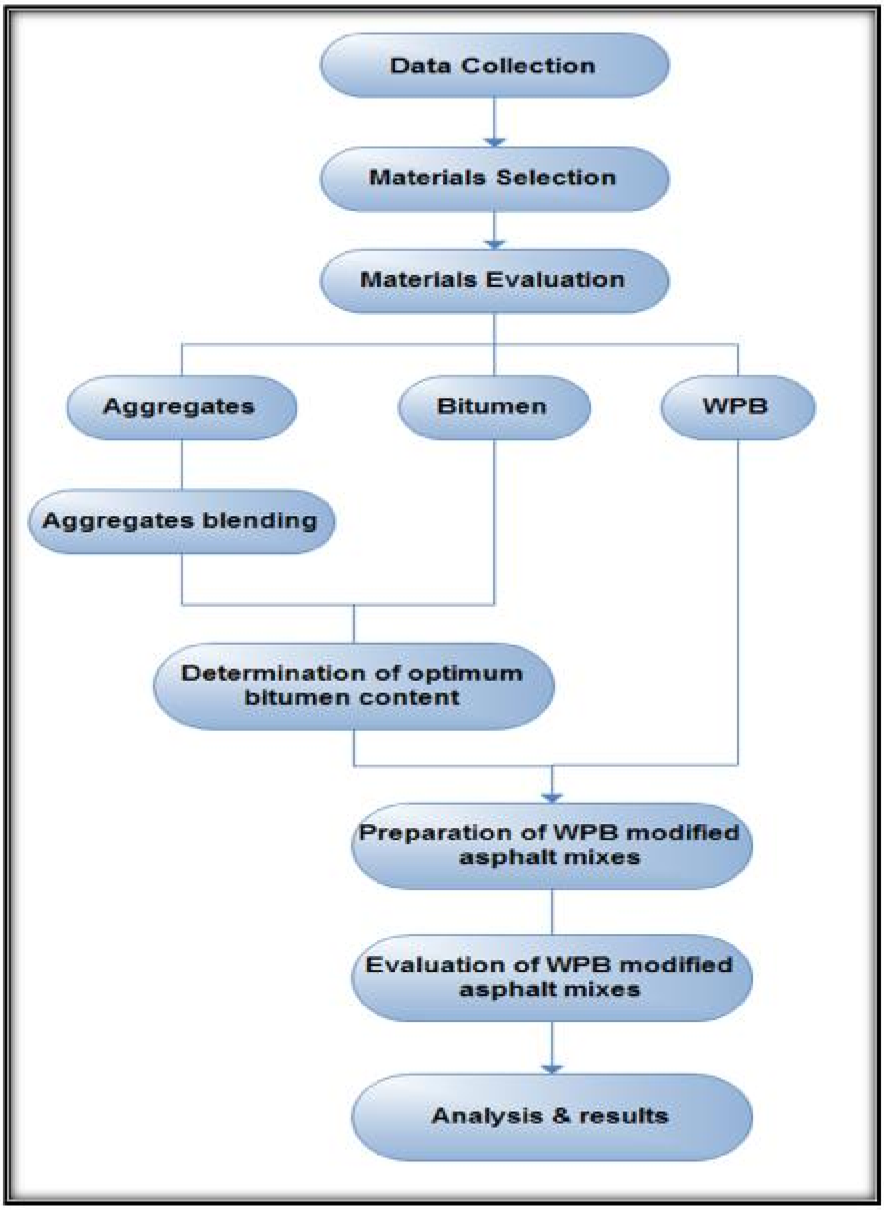

Figure (3.1): *Flow chart of laboratory testing procedure*

Table (3.1): *Main and local sources of used materials*

Material	Source	
	Main	Local
Aggregates	Crushed rocks (Egypt)	Al-Amal asphalt factory (Johr El-Deek- South west Gaza)
Bitumen	Egypt	Al-Farra factory (Rafah city)
Milled waste plastic bags	Local waste plastic bags	Al-Ramlawy plastic factory (Gaza city)

Figure (3.2): *Source of aggregates- Adasia (Al-Amal Asphalt mix factory)*

Figure (3.3): *Waste plastic bags (Al-Ramlway plastic factory)*

3.2 Materials properties

3.2.1 Bitumen properties

Asphalt binder 70/80 was used in this research. In order to evaluate bitumen properties number of laboratory tests have been performed such as: specific gravity, ductility, flash point, fire point, softening point and penetration.

3.2.1.1 Bitumen penetration test

- Test specification : ASTM D5-95
- Container dimension : 75 mm x 55mm
- Test results is listed in Table (3.2)

Table (3.2): *Bitumen penetration test results*

	Sample (1)			Sample (2)		
Trial	1	2	3	1	2	3
Initial (0.1 mm)	0	0	0	0	0	0
Final (0.1 mm)	71	69	70	69	71	72
Penetration value (0.1 mm)	71	69	70	69	71	72
	70			70.67		
	Average = 70.33					

3.2.1.2 Ductility test

- Test specification : ASTM D113-86
- Test results are listed in Table (3.3).
- Figure (3.4) show ductility test for a bitumen sample.

Table (3.3): *Bitumen ductility test results*

Sample	Ductility (cm)
A	140
B	149
C	145
Average	144.67

Figure (3.4): *Ductility test for a bitumen sample*

3.2.1.3 Softening point test

- Test specification : ASTMD36-2002
- Test results are listed in Table (3.4).
- Figure (3.5) show softening point test for bitumen samples.

Table (3.4): *Bitumen softening point results*

Sample	Softening point (C^o)
A	46.4
B	46.4
Average	46.4

Figure (3.5): *Softening point test for bitumen samples*

3.2.1.4 Flash and fire point tests

- Test specification : ASTM D92-90
- Test results is listed in Table (3.5)
- Flash Point: the lowest temperature at which the application of test flame causes the vapors from the bitumen to momentarily catch fire in the form of a flash.
- Fire Point: The lowest temperature at which the application of test flame causes the bitumen to fire and burn at least for 5 seconds.

Table (3.5): *Bitumen flash &fire point test results*

Flash point (C^o)	272
Fire point (C^o)	286

3.2.1.5 Specific gravity test

- Test specification : ASTMD D70
- Test results is listed in Table (3.6)

Table (3.6): *Specific gravity test results*

Weight of sample (gm)	30
Weight of Pycnometer + water at 25°C (gm)	1784.26
Weight of Pycnometer + water at 25°C + Sample (gm)	1784.935

$$S.G. = \frac{30}{(1784.26 + 30) - 1784.935} = 1.023 g / cm^3$$

3.2.1.6 Summary of bitumen properties

Table (3.7): *Summary of bitumen properties*

Test	Specification	Results	ASTM specifications limits
Penetration (0.01 mm)	ASTM D5-06	70.34	70-80 (70/80 binder grade)
Ductility (cm)	ASTM D113-86	144.67	Min 100
Softening point (°C)	ASTMD36-2002	46.4	(45 – 52)
Flash point (°C)	ASTM D92-02	272	Min 230° C
Fire point (°C)	ASTM D92-90	286	
Specific gravity (g/cm^3)	ASTMD D70	1.023	0.97-1.06

3.2.2 Waste plastics properties

Table (3.8): *Waste plastics properties*

Property	Detail
Plastic type	Grinded waste thin plastic packaging bags
Plastic material	Low density Polyethylene (LDPE)
Size (mm)	2.00 – 4.75
Density (g/cm^3)*	0.92
Melting point (°C)*	110

*. According to (Awwad and Shabeeb, 2007)

Figure (3.6): *Used grinded waste plastic*

3.2.3 Aggregates properties

Aggregates used in asphalt mix can be divided as shown in Table (3.9) and Figure (3.7).

Table (3.9): *Used aggregates types*

	Type of aggregate	Particle size (mm)
Coarse	Folia	0/ 19.0
	Adasia	0/ 12.5
	Simsimia	0/ 9.50
Fine	Trabiah	0/4.75
	Sand	0/0.6

Figure (3.7): *Used aggregates types*

In order to define the properties of used aggregates, number of laboratory tests have been done, these tests include:

a. Sieve Analysis(ASTM C 136)
b. Specific gravity test (ASTM C127).
c. Water absorption (ASTM C128)
d. Los Angles abrasion (ASTM C131)

Table (3.10) present aggregate tests results

Table (3.10): *Results of aggregates tests*

Test	Folia 0/ 19.0	Adasia 0/ 12.5	Simsimia 0/ 9.50	Trabia 0/4.75	Sand 0/0.6	Designation No.	Specification limits
Bulk dry S.G	2.51	2.49	2.54	2.67	2.58	ASTM : C127	--
Bulk SSD S.G	2.56	2.55	2.61	2.73	2.63		
Apparent S.G	2.66	2.65	2.73	2.85	2.72		
Effective S.G	2.58	2.57	2.64	2.76	2.65		
Absorption (%)	2.38	2.49	2.79	2.46	2.02	ASTM : C128	**< 5**
Abrasion value (%)	22.4		--	--	--	ASTM : C131	**< 40**

3.2.3.1 Sieve analysis

- Specification (ASTM C 136)
- Table (3.11) and figures (3.8 - 3.13) show aggregates sieve analysis results.

Table (3.11): *Aggregates sieve analysis results*

Sieve size (mm)	Sieve #	Sample passing %				
		Folia 0/ 19.0	Adasia 0/ 12.5	Simsimia 0/ 9.50	Trabia 0/4.75	Sand 0/0.6
19	3/4"	100.0	99.5	100.00	100.0	100.0
12.5	1/2"	1.1	71.4	100.00	100.0	100.0
9.5	3/8"	0.5	29.8	99.50	100.0	100.0
4.75	#4	0.5	4.5	40.20	96.0	100.0
2.00	#10	0.5	2.0	6.03	67.4	100.0
1.18	#16	0.5	1.8	5.03	49.3	100.0
0.6	#30	0.5	1.5	4.02	34.6	99.0
0.425	#40	0.5	1.5	4.02	29.0	67.6
0.3	#50	0.5	1.3	3.02	25.1	18.0
0.15	#100	0.4	0.8	2.01	20.5	0.2
0.075	#200	0.2	0.3	1.01	17.3	0.0
Pan	Pan	0.0	0.0	0.00	0.0	0.0

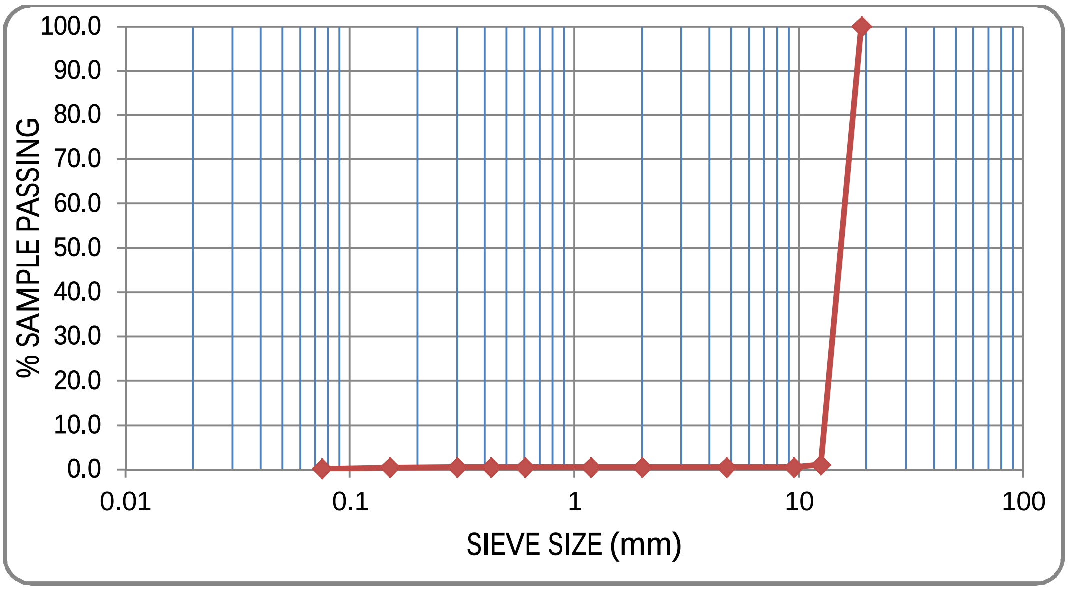

Figure (3.8): *Gradation curve (Folia 0/ 19.0)*

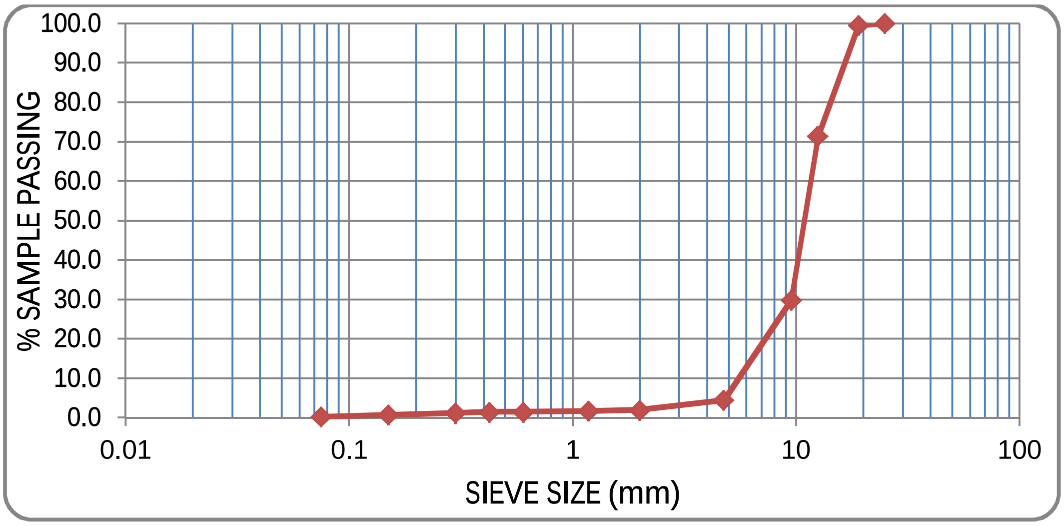

Figure (3.9): *Gradation curve (Adasia0/ 12.5)*

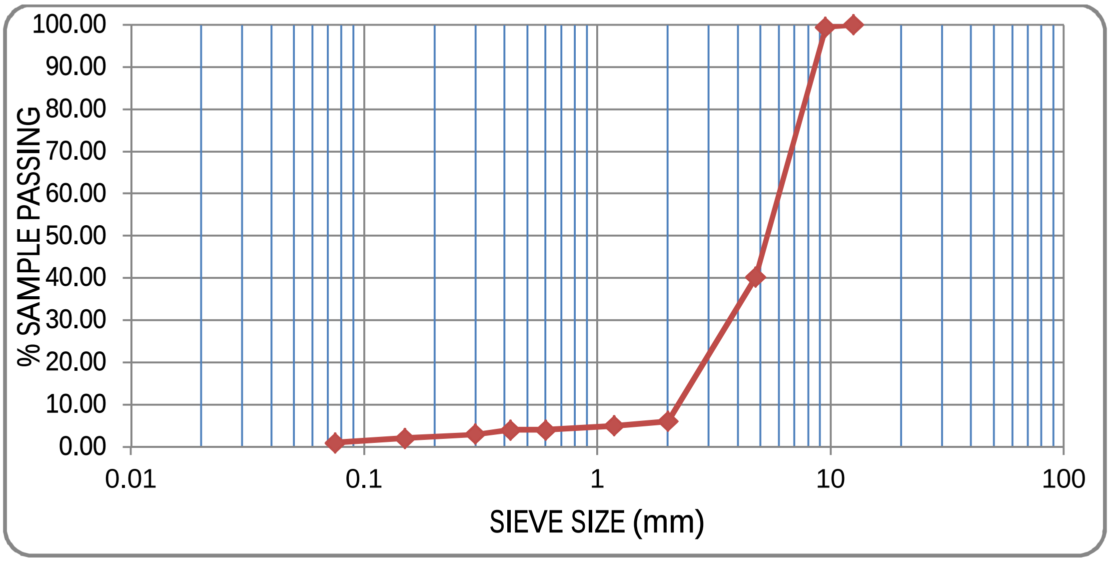

Figure (3.10): *Gradation curve (Simsimia 0/ 9.5)*

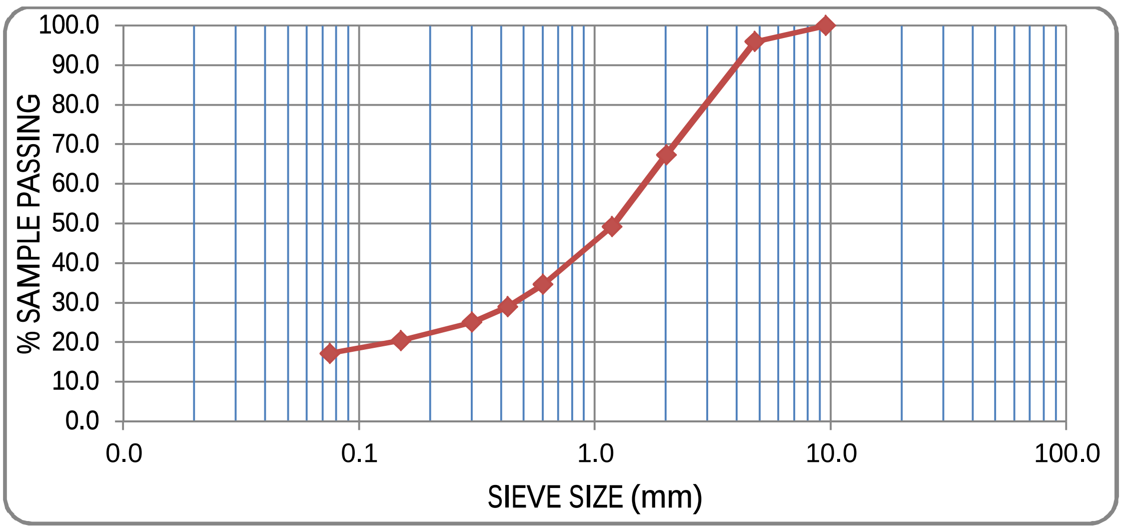

Figure (3.11): *Gradation curve (Trabia 0/ 4.75)*

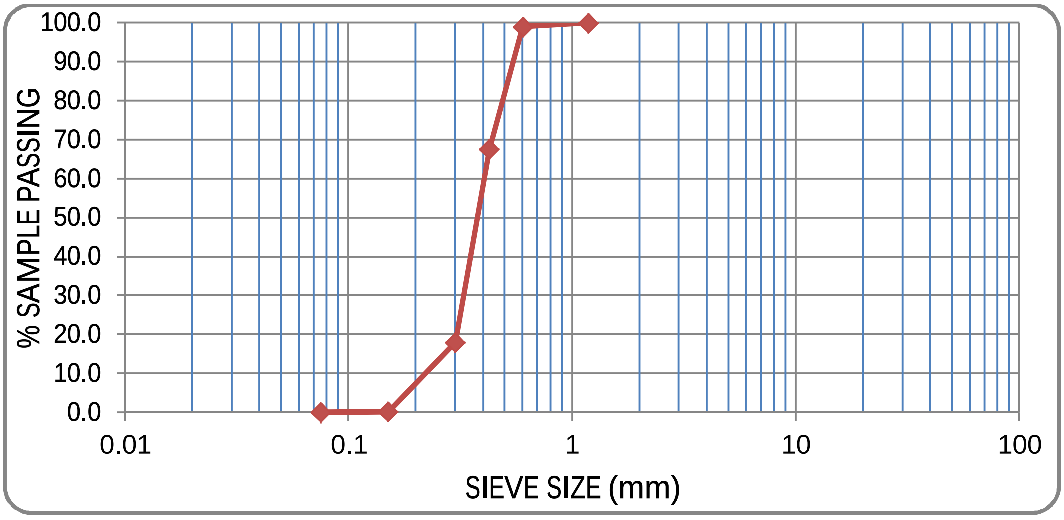

Figure (3.12): *Gradation curve (Sand 0/ 0.6)*

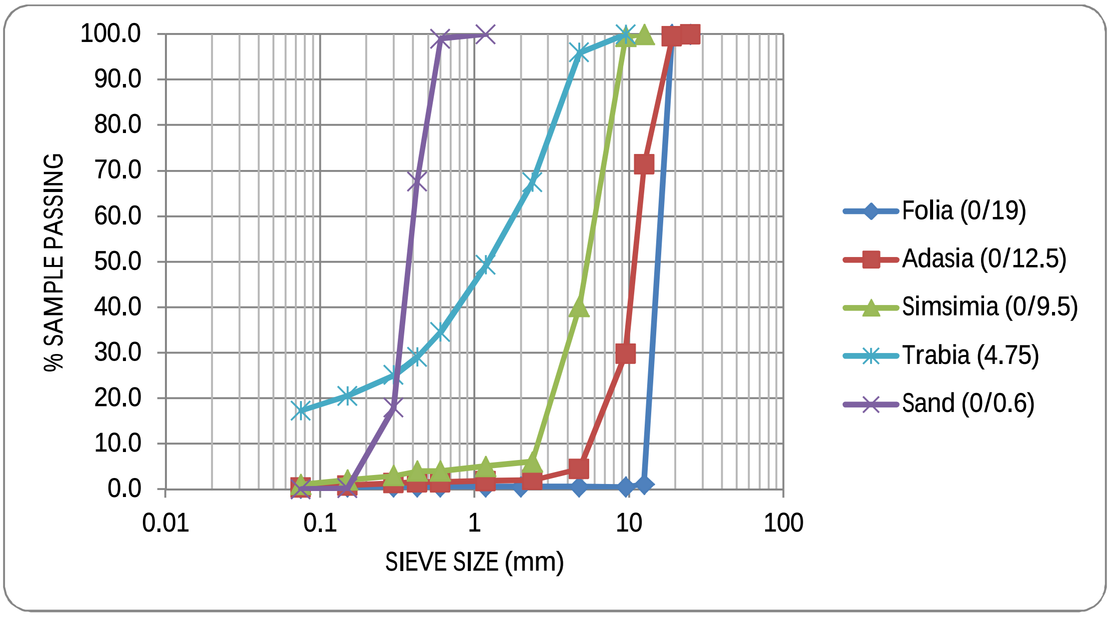

Figure (3.13): *Aggregates gradation curves*

3.3 Testing program

3.3.1 Blending of aggregates

Asphalt mix requires the combining of two or more aggregates, having different gradations, to produce an aggregate blend that meets gradation specifications for a particular asphalt mix.

Available aggregate materials (0/19), (0/12.5), (0/9.5), (0/4.75) and sand are integrated in order to get the proper gradation within the allowable limits according to ASTM specifications using mathematical trial method. This method depends on suggesting different trial proportions for aggregate materials from whole gradation. The percentage of each size of aggregates is to be computed and compared to specification limits. If the calculated gradation is within the allowable limits, no further adjustments need to be made; if not, an adjustment in the proportions must be made and the calculations repeated. The trials are continued until the percentage of each size of aggregate are within allowable limits (Jendia, 2000). Aggregates blending results are presented in chapter (4) and in more detail in Appendix (B).

3.3.2 Marshal test

Marshall Method for designing hot asphalt mixtures is used to determine the optimum bitumen content to be added to specific aggregate blend resulting a mix where the desired properties of strength and durability are met. According to standard 75-blow Marshal design method designated as (ASTM D 1559-89) a number of 15 samples each of 1200 gm in weight were prepared using five different bitumen contents (from 4 - 6% with 0.5 % incremental). Three samples were used to prepare asphalt mixture with one-bitumen content to have an average value of Marshal Stability, bulk density and flow. Figure (3.14) show Marshal Specimens for different bitumen percentages.

Marshall Properties of the asphalt mix such as stability, flow, density, air voids in total mix, and voids filled with bitumen percentage are obtained for various bitumen contents. The following graphs are then plotted:

a) Stability vs. Bitumen Content;
b) Flow vs. Bitumen Content;
c) Bulk Specific Gravity vs. bitumen Content;
d) Air voids (Va) vs. Bitumen Content;
e) Voids Filled with Bitumen (VFB) vs. Bitumen Content

These graphs are utilized to obtain optimum bitumen content.

Figure (3.14): *Marshal specimens for different bitumen percentages*

3.3.2.1 Determination of optimum bitumen content (OBC)

The optimum bitumen content (OBC) for proposed mix is the average of three values of bitumen content (Jendia, 2000), which include:

a) Bitumen content at the highest stability $(\% \, m_b)_{Stability}$

b) Bitumen content at the highest value of bulk density $(\% \, m_b)_{bulk\ density}$

c) Bitumen content at the median of allowed percentages of air voids (Va = 3-5%) $(\% \, m_b)_{Va}$

Marshal graphs are utilized to obtain these three values.

Optimum bitumen content (OBC) % =

$$\frac{(\%\,\text{mb})_{\text{Stability}} + (\%\,\text{mb})_{\text{bulk density}} + (\%\,\text{mb})_{\text{Va}}}{3}$$

Properties of the asphalt mix using optimum bitumen content such as stability, flow, Va, bulk density and VMA are obtained and checked against specifications range.

3.4 Preparation of asphalt mix modified with waste plastic bags

There are many different methods for utilization of waste plastic materials in asphalt mix. In this study; the aim of adding waste plastic bags (WPB) to asphalt mix is to provide an aggregate coating material and not to enhance bitumen properties as bitumen modifier.

After obtaining OBC, 32 samples were prepared at OBC to evaluate the effect of adding WPB to asphalt mixture samples by considering eight proportions of WPB (0, 6, 8, 10, 12, 14, 16 and 18% by the weight of OBC)

The procedure of incorporating WPB in asphalt mix can be summarized as follows:

a) WPB have to be grinded then sieved to have a granular size (2.00 – 4.75 mm).
b) Requisite amount of grinded WPB is mixed with course aggregates (Folia (0/19), Adasia (0/12.5) and Simsimia (0/9.5)). WPB and course aggregates mix is heated at (185-190)^{o}C for approximately (2.5) hours. The heating temperature and duration of aggregates were chosen based on many experimental trials to be hot enough to melt WPB that it would stick to the aggregate surfaces and leave textured surface with good adhesion between coated aggregates. Figure (3.15) show the addition of WPB to aggregate mix before heating.
c) Fine aggregates are heated at the same temperature for the same period as in part (b) but in separated pan. Experimental trials show that it's better to separate fine aggregates from mix in part (b) when heating because they would form an insulating layer coating melted plastic which may weaken adhesion between course aggregates and melted plastics.
d) Requisite amount of bitumen is heated until it reaches 150 ^{o}C.
e) WPB and course aggregates are mixed with fine aggregates followed by addition of hot bitumen at OBC. All ingredients are mixed vigorously to form a homogeneous asphalt mixture.
f) After preparing modified asphalt mix, specimens are prepared, compacted, and tested according to standard 75-blow Marshal Method designated as (ASTM D 1559-89). Figure (3.16) show Marshal Specimens modified with different percentages of WPB.

Figure (3.15): *Adding WPB to aggregates before heating*

Figure (3.16): *WPB modified Marshal Specimens*

Chapter 4. Results and Data Analysis

4.1 Introduction

Results of laboratory work had been obtained and analyzed in order to achieve study objectives which include studying the effect of adding different percentages of WPB on the mechanical properties of asphalt mix and identify the optimum percent of WPB to be added to hot mix asphalt.

Laboratory work results are presented in this chapter in three stages. First, handle the results of blending aggregates to obtain asphalt binder course gradation curve. Second stage, Marshal Test is carried out with different percentages of bitumen which are (4.0, 4.5, 5.0, 5.5 and 6.0%) and the results are analyzed in order to obtain the optimum bitumen content (OBC).

After obtaining OBC, the following step is to study the effect of adding different percentages of WPB on asphalt mix properties which are (6, 8, 10, 12, 14, 16 and 18%) by the weight of OBC. Marshal test results for modified asphalt mixes are analyzed and finally the optimum WPB modifier content is obtained.

4.2 Blending of aggregates

The final proportion of each aggregate material in asphalt binder course is shown in Table (4.1). The proposed aggregates gradation curve is found to be satisfying ASTM specification for asphalt binder course gradation. The gradation of final aggregate mix with ASTM gradation limits is presented in Table (4.2) and Figure (4.1).

Table (4.1): *Proportion of each aggregate material from proposed mix*

Aggregates type	Size (mm)	Proportion from proposed mix (%)
Folia	0/19	**14.0**
Adasia	0/12.5	**19.0**
Simsimia	0/9.5	**27.0**
Trabiah	0/4.75	**34.0**
Sand	0/0.60	**6.0**
Sum		**100**

Table (4.2): *Gradation of proposed mix with ASTM specifications limits*

Sieve size (mm)	% Passing	ASTM D5315 specification limits (%)	
		Min	Max
25	**100.00**	100	100
19	**99.93**	90	100
12.5	**80.76**	67	85
9.5	**72.65**	56	80
4.75	**50.47**	35	65
2.36	**31.04**	23	49
1.18	**24.59**	15	37
0.6	**19.21**	8	26
0.425	**15.38**	6	22
0.3	**10.75**	5	19
0.15	**7.74**	3	14
0.075	**6.24**	2	8

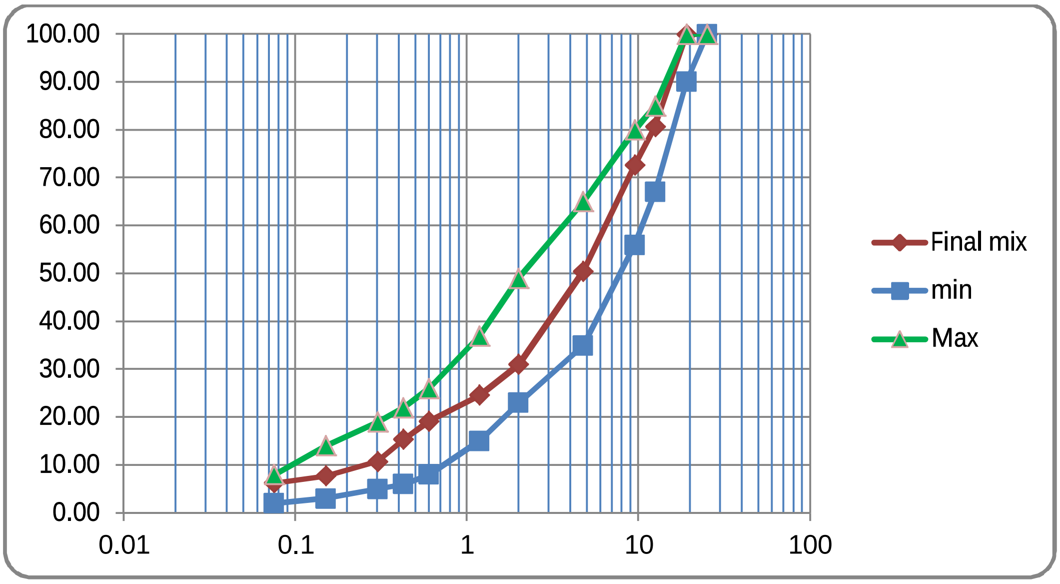

Figure (4.1): *Gradation of final aggregates mix with ASTM specification range*

4.3 Marshal test

As discussed in chapter (3). A number of 15 samples each of 1200 gm in weight were prepared using five different bitumen contents (from 4 - 6% with 0.5 % incremental) in order to obtain the optimum bitumen content (OBC). Table (4.3) and Figures (4.2–4.7) show summary of Marshal Test results. Further details are presented in Appendix (D).

Table (4.3): *Summary of Marshal Test results*

Bitumen % (By total weight)	Sample No.	Corr. Stability (Kg)	Flow (mm)	ρ_A (g/cm3)	Va (%)	Vb (%)	VMA (%)	VFB (%)
4	1	1517.59	3.37	2.31	7.46	9.03	16.49	54.76
	2	1412.64	3.13	2.28	8.64	8.91	17.55	50.79
	3	1384.27	2.47	2.32	7.30	9.04	16.34	55.35
	Average	**1438.17**	**2.99**	**2.31**	**7.80**	**9.00**	**16.79**	**53.63**
4.5	1	1550.98	3.58	2.34	5.52	9.15	14.67	62.38
	2	1384.11	2.87	2.32	6.38	9.07	15.45	58.69
	3	1443.38	2.52	2.34	5.83	9.12	14.95	60.98
	Average	**1459.49**	**2.99**	**2.33**	**5.91**	**9.11**	**15.02**	**60.69**
5	1	1445.76	2.99	2.35	4.40	9.19	13.59	67.62
	2	1515.28	3.34	2.35	4.78	9.15	13.94	65.67
	3	1531.58	3.13	2.36	4.37	9.19	13.56	67.76
	Average	**1497.54**	**3.15**	**2.35**	**4.52**	**9.18**	**13.70**	**67.02**
5.5	1	1608.05	3.50	2.35	4.02	9.16	13.18	69.49
	2	1355.95	3.39	2.36	3.59	9.20	12.79	71.92
	3	1257.48	2.83	2.33	4.53	9.11	13.64	66.77
	Average	**1407.16**	**3.24**	**2.35**	**4.05**	**9.15**	**13.20**	**69.39**
6	1	1551.83	4.26	2.33	3.85	9.11	12.96	70.28
	2	1349.94	4.08	2.34	3.76	9.12	12.87	70.82
	3	1286.59	4.15	2.33	3.99	9.09	13.08	69.50
	Average	**1396.12**	**4.18**	**2.33**	**3.87**	**9.11**	**12.97**	**70.20**

(1) r_A Bulk Density

(2) Va% Air voids content

(3) Vb % Percent volume of bitumen

(4) VMA% Percent voids in Mineral Aggregates

(5) VFB% Percent Voids Filled with Bitumen

4.3.1 Stability – bitumen content relationship

Stability is the maximum load required to produce failure of the specimen when load is applied at constant rate 50 mm / min (Jendia, 2000). In Figure (4.2) stability results for different bitumen contents are represented. Stability of asphalt mix increases as the bitumen content increase till it reaches the peak at bitumen content 4.7% then it started to decline gradually at higher bitumen content.

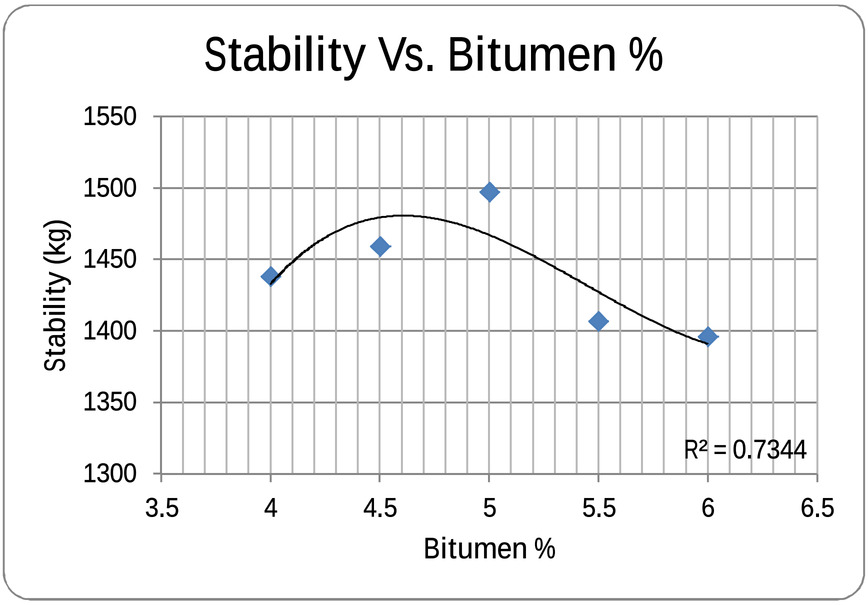

Figure (4.2): *Stability vs. bitumen content*

4.3.2 Flow – bitumen content relationship

Flow is the total amount of deformation which occurs at maximum load (Jendia, 2000). In Figure (4.3) Flow results for different bitumen contents are represented. Flow of asphalt mix increases as the bitumen content increase till it reaches the peak at the max bitumen content 6 %.

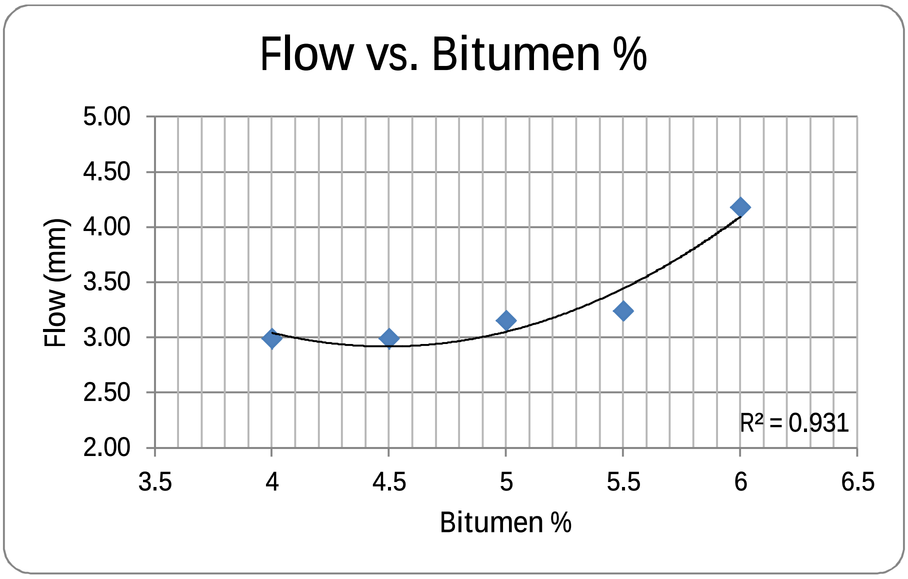

Figure (4.3): *Flow vs. bitumen content*

4.3.3 Bulk density – bitumen content relationship

Bulk density is the actual density of the compacted mix. In Figure (4.4) Bulk density results for different bitumen contents are represented. Bulk density of asphalt mix increases as the bitumen content increase till it reaches the peak (2.35 g/cm^3) at bitumen content 5.25 % then it started to decline gradually at higher bitumen content.

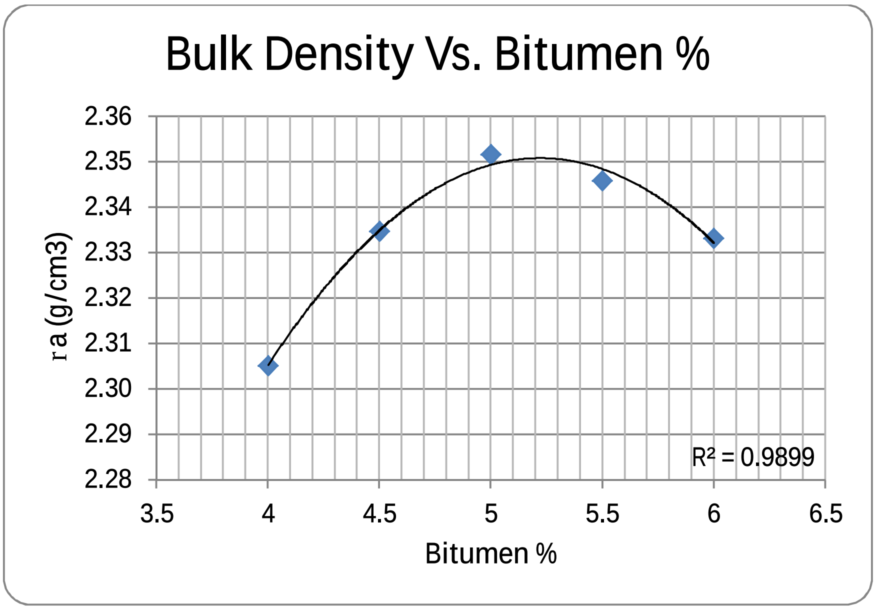

Figure (4.4): *Bulk density vs. bitumen content*

4.3.4 Va% – bitumen content relationship

Va % is the percentage of air voids by volume in specimen or compacted asphalt mix (Jendia, 2000). In Figure (4.5) Va% results for different bitumen contents are represented. Maximum air voids content value is at the lowest bitumen percentage (4%), Va% decrease gradually as bitumen content increase due to the increase of voids percentage filled with bitumen in the asphalt mix.

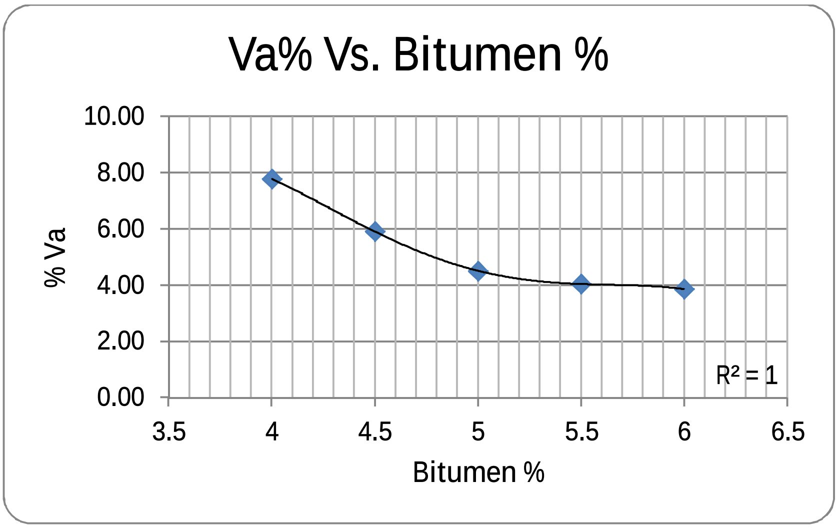

Figure (4.5): *Mix air voids proportion vs. bitumen content*

4.3.5 VFB% – bitumen content relationship

Voids Filled with Bitumen (VFB) is the percentage of voids in mineral aggregates filled with bitumen (Jendia, 2000). In Figure (4.6) VFB% results for different bitumen contents are represented. Minimum VFB content value is at the lowest bitumen percentage (4%), VFB% increase gradually as bitumen content increase due to the increase of voids percentage filled with bitumen in the asphalt mix.

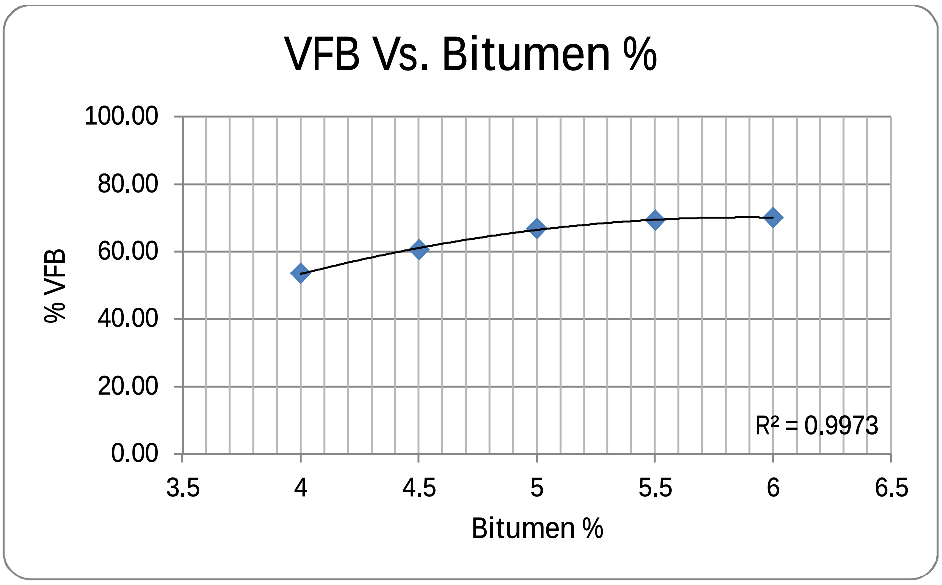

Figure (4.6): *Voids filled bitumen proportion vs. bitumen content*

4.3.6 VMA% – bitumen content relationship

Voids in Mineral Aggregates (VMA) is the percentage of voids volume of the in the aggregates before adding bitumen or the sum of the percentage of voids filled with bitumen and percentage of air voids remaining in asphalt mix after compaction (Jendia, 2000). In Figure (4.7) VMA% results for different bitumen contents are represented. Max voids in mineral aggregates content is at the lowest bitumen percentage (4%), VMA% decrease gradually as bitumen content increase and fill higher percentage of voids in the asphalt mix.

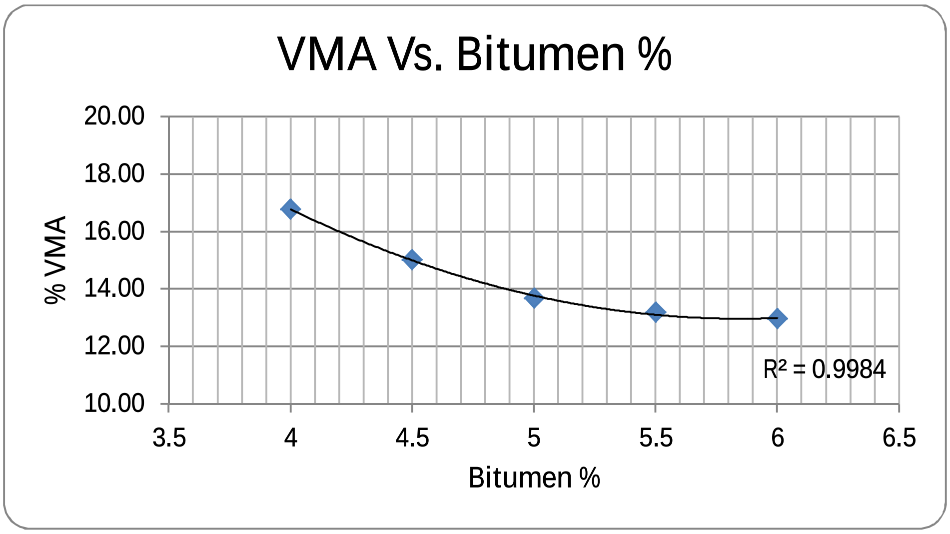

Figure (4.7): *Voids of mineral aggregates proportion vs. bitumen content*

4.3.7 Determination of optimum bitumen content (OBC)

Figures (4.2, 4.4 and 4.5) are utilized to find three values respectively.

- Bitumen content at the highest stability $(\% \ m_b)_{Stability}$ = 4.70 %
- Bitumen content at the highest value of bulk density $(\% \ m_b)_{bulk\ density}$ = 5.25%
- Bitumen content at the median of allowed percentages of air voids $(\% \ m_b)_{Va}$ = 5.25%
- **Optimum bitumen content (OBC)** = $\frac{4.70 + 5.25 + 5.25}{3} = 5.10\ \%$

All results of asphalt mix with OBC satisfy Municipality of Gaza (MOG) and Asphalt Institute specifications requirements as shown in Table (4.4).

Table (4.4): *Properties of the asphalt mix using optimum bitumen content*

Property	Value	Local Spec. (MOG, 1998)		International Spec. (Asphalt Institute, 1998)	
		Min.	Max.	Min.	Max.
Stability (kg)	1472	900	*	817	*
Flow (mm)	3.1	2	4	2	3.5
Void in Mineral aggregate (VMA)%	13.8	13.5	*	13	*
Air voids (Va)%	4.3	3	7	3	5
Bulk density (gm/cm^3)	2.35	2.3	*	2.3	*

4.4 Effect of adding WPB on the mechanical properties of asphalt mix

4.4.1 Phase (I): Conventional asphalt mix

The mechanical properties of asphalt mix prepared with OBC (5.10 %) without addition of WPB is shown in Table (4.5).

Table (4.5): *Mechanical properties of asphalt mix without addition of WPB*

Sample No.	Bitumen % (By total weight)	Corr. Stability (Kg)	Flow (mm)	ρ_A (g/cm3)	Va (%)	Vb (%)	VMA (%)	VFB (%)
1	5.1	1509.04	2.89	2.37	3.87	11.83	15.70	75.37
2	5.1	1529.97	2.93	2.35	4.63	11.74	16.36	71.74
3	5.1	1527.65	3.08	2.36	3.94	11.82	15.77	74.99
Average	**5.1**	**1522.222**	**2.97**	**2.36**	**4.15**	**11.80**	**15.94**	**74.03**

4.4.2 Phase (II): Asphalt mix with (WPB)

According to procedure previously illustrated in chapter (3), 28 samples were prepared at OBC to evaluate the effect of adding WPB to asphalt mixture samples by considering seven proportions of WPB (6, 8, 10, 12, 14, 16 and 18% by the weight of OBC). Table (4.6) shows the mechanical properties of asphalt mix using different percentages of WPB (By weight of OBC). Further details are presented in Appendix (E).

Table (4.6): *Mechanical properties of asphalt mix with WPB*

WPB % (By weight of OBC)	Sample No.	Bitumen % (By total weight)	Corr. Stability (Kg)	Flow (mm)	ρA (g/cm3)	Va (%)	Vb (%)	VMA (%)	VFB (%)
6	1	5.1	1692.60	3.11	2.35	4.46	11.69	16.16	72.37
	2	5.1	1656.04	2.58	2.34	4.77	11.66	16.42	70.98
	3	5.1	1933.21	3.24	2.36	3.75	11.78	15.53	75.87
	Average	**5.1**	**1760.619**	**2.97**	**2.35**	**4.33**	**11.71**	**16.04**	**73.07**
8	1	5.1	1902.09	3.35	2.34	4.47	11.66	16.12	72.29
	2	5.1	1841.57	3.11	2.33	4.65	11.63	16.29	71.43
	3	5.1	1556.02	2.88	2.35	4.09	11.70	15.79	74.12
	Average	**5.1**	**1766.558**	**3.11**	**2.34**	**4.40**	**11.66**	**16.07**	**72.62**
10	1	5.1	2009.27	2.83	2.34	4.46	11.69	16.15	72.39
	2	5.1	2071.04	3.14	2.35	4.26	11.71	15.98	73.31
	3	5.1	1840.72	3.68	2.35	4.33	11.71	16.03	73.00
	Average	**5.1**	**1973.676**	**3.22**	**2.35**	**4.35**	**11.70**	**16.05**	**72.90**
12	1	5.1	1914.53	3.21	2.35	4.32	11.71	16.02	73.07
	2	5.1	1938.55	3.59	2.35	4.14	11.73	15.87	73.89
	3	5.1	2102.18	3.71	2.33	5.14	11.61	16.75	69.30
	Average	**5.1**	**1985.086**	**3.50**	**2.34**	**4.53**	**11.68**	**16.22**	**72.09**
14	1	5.1	1985.10	3.28	2.34	4.94	11.65	16.59	70.23
	2	5.1	2066.24	3.21	2.34	4.67	11.68	16.35	71.43
	3	5.1	2047.24	3.72	2.34	4.68	11.68	16.36	71.39
	Average	**5.1**	**2032.858**	**3.40**	**2.341**	**4.76**	**11.67**	**16.43**	**71.02**
16	1	5.1	1926.04	3.99	2.32	4.61	11.56	16.17	71.51
	2	5.1	2058.13	4.27	2.31	5.03	11.51	16.54	69.60
	3	5.1	1808.51	3.38	2.32	4.54	11.57	16.11	71.83
	Average	**5.1**	**1930.893**	**3.88**	**2.32**	**4.72**	**11.55**	**16.27**	**70.98**
18	1	5.1	1873.72	3.72	2.33	4.46	11.59	16.05	72.24
	2	5.1	1653.00	3.28	2.31	5.03	11.52	16.55	69.62
	3	5.1	1655.40	5.11	2.31	5.06	11.52	16.58	69.46
	Average	**5.1**	**1727.37**	**4.04**	**2.32**	**4.85**	**11.54**	**16.39**	**70.44**

4.4.2.1 Stability – WPB content relationship

Generally, the stability of modified asphalt mixes is higher than the conventional asphalt mix (1522.2 kg). All the values of stability for different modifier percentages are higher than stability of conventional mix. The maximum stability value is found nearly (2033 kg) at WPB content around (14%). Figure (4.8) shows that the stability of modified asphalt mix increases as the WPB content increases till it reaches the peak at (14 %) WPB content then it started to decline steeply at higher WPB content.

The improvement of stability in WPB modified asphalt mixes can be explained as a result of the better adhesion developed between bitumen and WPB coated aggregates due to intermolecular bonding, these intermolecular attractions enhanced strength of asphalt mix, which in turn help to enhance durability and stability of the asphalt mix (Sabina *et al.*, 2009).

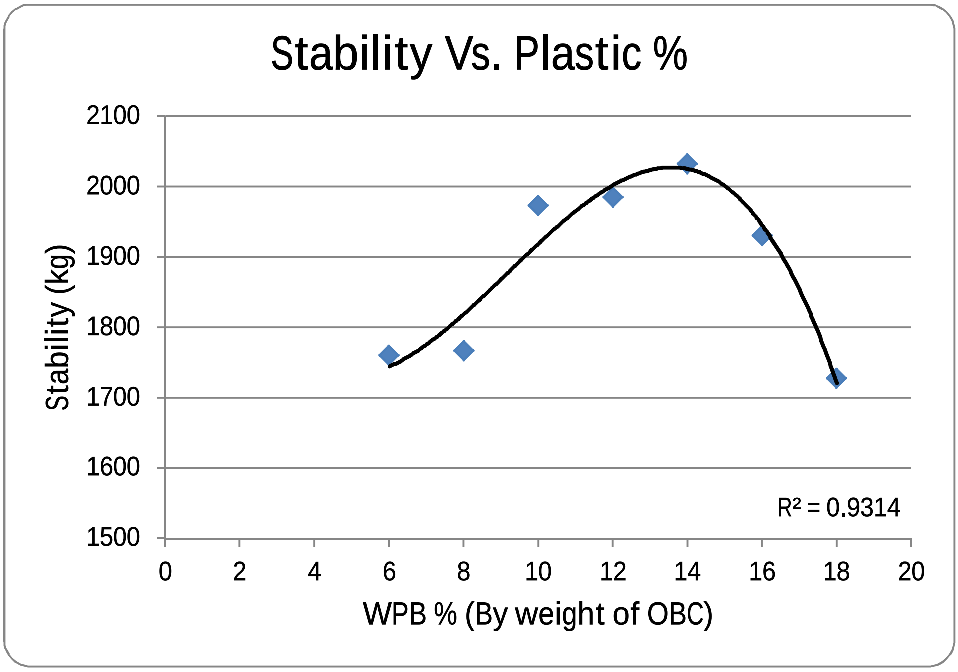

Figure (4.8): *Asphalt mix Stability – WPB content relationship*

4.4.2.2 Flow – WPB content relationship

Generally, the flow of modified asphalt mix is higher than the conventional asphalt mix (2.97 mm). Figure (4.9) shows that the flow increases continuously as the WPB modifier content increase. The flow value extend from (3mm) till it reach (4mm) at WPB content (18%).

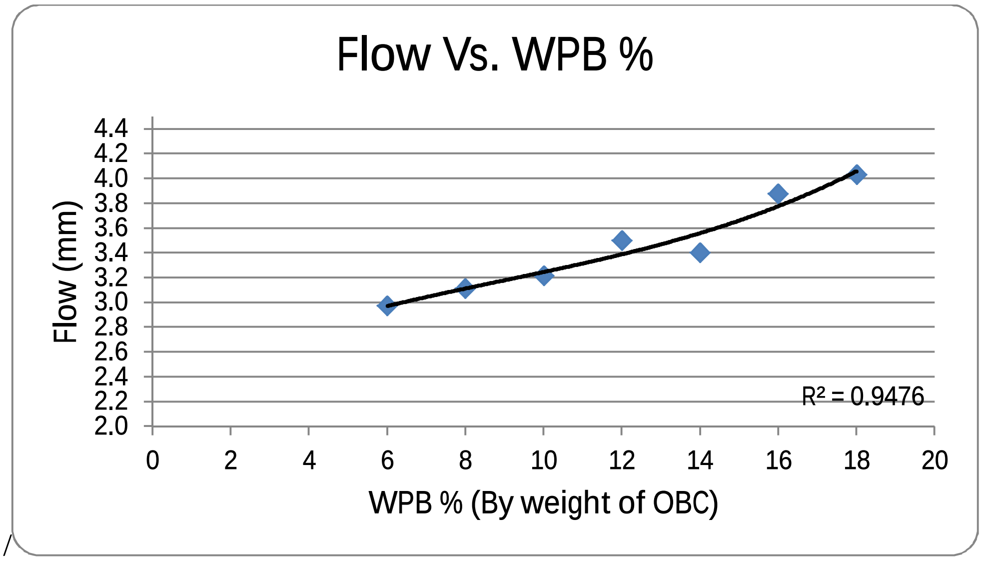

Figure (4.9): *Asphalt mix flow – WPB content relationship*

4.4.2.3 Bulk density – WPB content relationship

The bulk density of WPB modified asphalt mix is lower than the conventional asphalt mix (2.36 g/cm^3). The general trend shows that the bulk density decreases as the WPB content increase. The maximum bulk density is (2.35 g/cm^3) at WPB content (6%) and the minimum bulk density is (2.313 g/cm^3) at WPB (18%). This decrease of bulk density can be explained to be as a result of the low density of added plastic material. Figure (4.10) show the curve which represents asphalt mix bulk density – WPB content relationship.

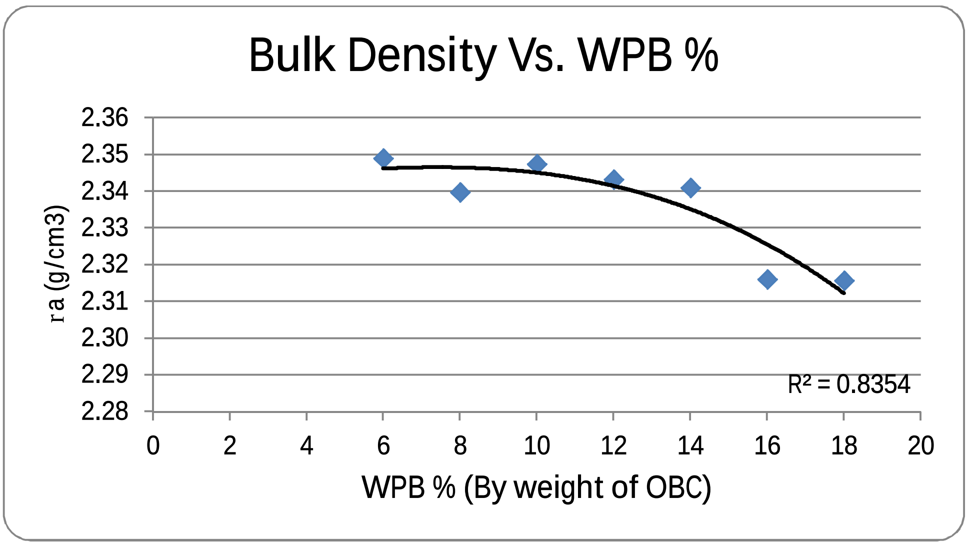

Figure (4.10): *Asphalt mix bulk density – WPB content relationship*

4.4.2.4 Air voids (Va) – WPB content relationship

In general, the air voids proportion of modified asphalt mixes is higher than conventional asphalt mix (4.15 %). Va % of modified asphalt mixes increases gradually as the WPB content increase till it reaches the highest Va% value at 18% WPB. Generally modified asphalt mixes have Va% content within specifications range. Figure (4.11) show the curve which represents asphalt mix air voids – WPB content relationship.

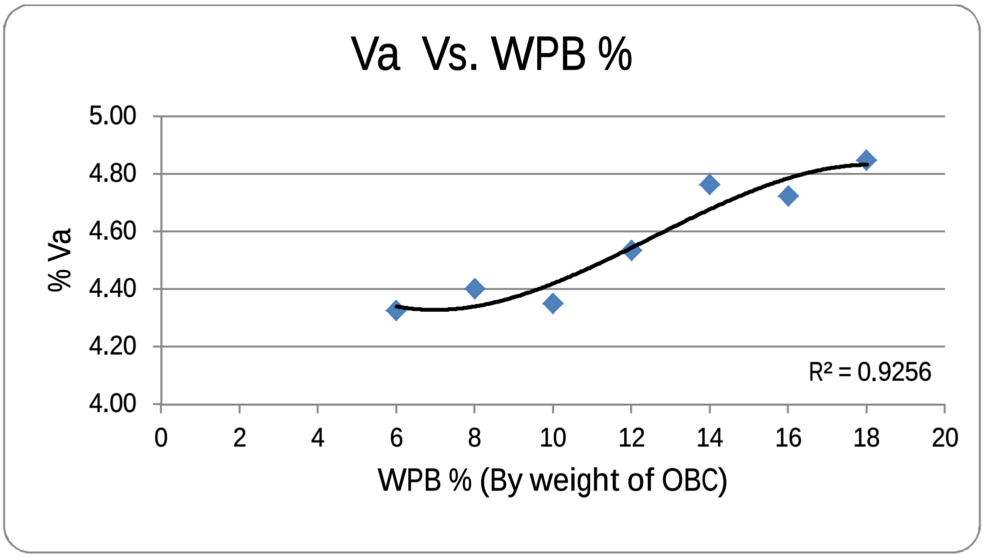

Figure (4.11): *Asphalt mix air voids – WPB content relationship*

4.4.2.5 Voids in mineral aggregates (VMA) – WPB content relationship

The voids in mineral aggregates percentage VMA% for asphalt mix is affected by air voids in asphalt mix Va and voids filled with bitumen Vb. VMA% of modified asphalt mixes is generally higher than conventional asphalt mix (15.94 %). VMA % of modified asphalt mixes increases as the WPB content increase, it reaches (16.38%) at WPB content (18%). Figure (4.12) show the curve which represents asphalt mix VMA% – WPB content relationship.

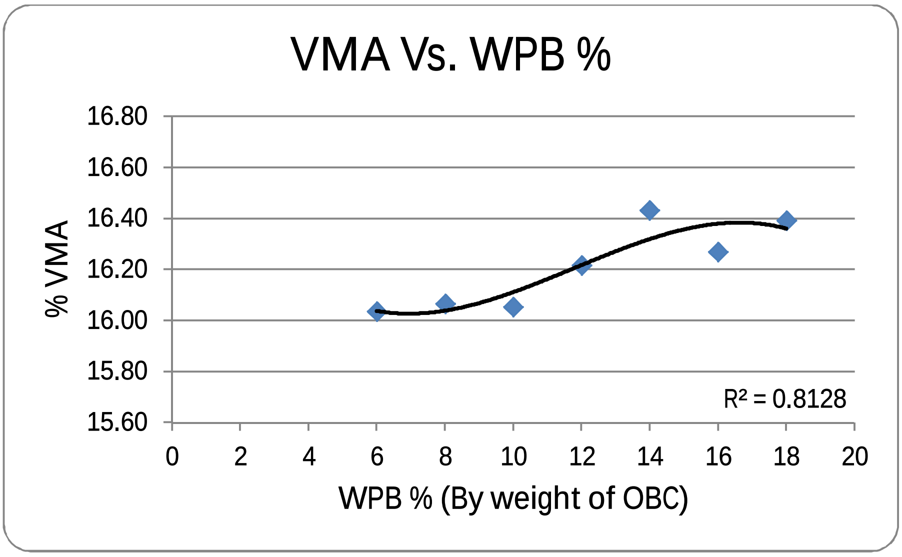

Figure (4.12): *Asphalt mix voids of mineral aggregates (VMA) – WPB content relationship*

4.4.3 Optimum modifier content

A set of controls is recommended in order to obtain the optimum modifier content that produce an asphalt mix with the best mechanical properties (Jendia, 2000). Asphalt mix with optimum modifier content satisfies the following:

- Maximum stability
- Maximum bulk density
- Va % within the allowed range of specifications.

Figures (4.8, 4.10 and 4.11) are utilized to find WPB percentages which satisfy these three controls. The WPB percentages which satisfy controls are summarized in Table (4.7).

Table (4.7): *Summary of controls to obtain optimum modifier content*

Property	WPB (By OBC Weight)
Maximum stability	14 %
Maximum bulk density	6 %
Va % within the allowed range of specifications	8 %

- The Optimum WPB content is the average of the previous five WPB contents.

Optimum WPB content (By OBC weight) $= \frac{14+6+8}{3} \sim = 9\ \%$

4.4.4 Comparison of control mix with WPB modified mix

A comparison of the mechanical properties of WPB modified asphalt mix at the optimum WPB content (9 % by OBC weight) and properties of the conventional asphalt mix is shown in Table (4.8). Minimum and maximum allowed limits are also presented according to Municipality of Gaza (MOG) specifications, and Asphalt Institute specifications in Table (4.9).

Table (4.8): *Comparison of WPB modified asphalt mix and conventional mix properties*

Property	Conventional asphalt mix	(9%) WPB modified asphalt mix (By OBC weight)	Change amount
Optimum Bitumen content (%)	5.1	5.1	-
Stability (kg)	1522	1880	+ 23.52 %
Flow (mm)	2.97	3.19	+ 7.41 %
Stiffness (kg/mm)	512.46	589.34	+ 15.00 %
Void in Mineral aggregate (VMA)%	15.94	16.06	+ 0.75 %
Air voids (Va)%	4.15	4.36	+ 5.06 %
Bulk density (gm/cm^3)	2.36	2.346	- 0.60 %

Table (4.9): *Properties of WPB modified asphalt mix with specifications range*

Property	(9 %) WPB modified asphalt mix (By OBC weight)	Local Spec. (MOG, 1998)		International Spec. (Asphalt Institute, 1997)	
		Min.	Max.	Min.	Max.
Stability (kg)	1880	900	*	817	*
Flow (mm)	3.19	2	4	2	3.5
Void in Mineral aggregate (VMA)%	16.06	13.5	*	13	*
Air voids (Va)%	4.36	3	7	3	5
Bulk density (gm/cm^3)	2.346	2.3	*	2.3	*

It's clearly shown that asphalt mix modified with (9 % WPB by OBC weight) have higher stability and stiffness compared to the conventional asphalt mix, other properties of modified mix are still within the allowed range of the specifications. Slight increase of flow and air voids in modified asphalt mix is exhibited while VMA% and bulk density are approximately the same for the two asphalt mixes.

Melted WPB provide a rougher surface texture for aggregate particles in modified asphalt mix that would enhance asphalt mix engineering properties due to improved adhesion between bitumen and WPB coated aggregates. Improved stability would positively influence the fatigue and rutting resistance of the modified asphalt mix leading to more durable asphalt pavement (Awwad & Shabeeb, 2007; Sabina *et al.*, 2009)

As shown in Table (4.9) it’s obvious that modified asphalt mix with 9% WPB by weight of OBC satisfy the requirements of Municipality of Gaza (MOG) specifications, and Asphalt Institute specifications for all tested properties.

4.4.5 Required WPB quantity

In order to imagine how much WPB will be required for section of road when using WPB modified asphalt mix. The following example would be useful.

Example: Road section with the following parameters

- Width = 10 m
- Length = 1 km
- Asphalt binder course layer with 6 cm depth
- Density of modified asphalt mix = 2.346 g/cm^3 = 2.346 ton/m^3
- OBC = 5.1 %
- WPB content = 9 % (By weight of OBC)

WPB weight required for the section = WPB content x Density x Volume

= 0.09 x 0.051 x 2.346 x 10 x 1000 x 0.06 = 6.46 ton

From previous example it's obvious that asphalt pavement consumes large amount of raw materials and considerable amount of WPB can be reused in valuable application rather than disposal.

4.4.6 Cost analysis

In general there is no modification in the mechanical structure of the asphalt mix factory to produce WPB modified asphalt mix. The following cost analysis was conducted to compare the cost of the conventional asphalt mix and WPB modified asphalt mix.

a) Conventional mix

- Cost of conventional asphalt mix = 120 $ / Ton

b) WPB modified asphalt mix

- Cost of WPB modified asphalt mix = Cost of conventional asphalt mix + cost of added material – cost of asphalt mix substituted by added material
- Required weight of WPB material per ton of asphalt mix=

  WPB % x OBC% x 1 ton = 9 % x 5.1 % x 1 = 0.0051 ton = 4.6 kg
- Cost of one kg of WPB = 0.6 $
- Cost of one kg of conventional asphalt mix = 120/1000 = 0.12 $
- Cost of WPB per ton of asphalt mix = 4.6 x 0.6 = 2.76 $
- Cost of asphalt mix substituted by WPB material = 4.6 x 0.12 = 0.55 $
- Cost of WPB modified asphalt mix = 120 + 2.76 – 0.55 = 122.2 $

There is a slight increase of the cost of WPB modified asphalt mix compared to conventional asphalt mix = 2.2 $/ton. This increase of cost can be accepted due to the advantages offered by the modified asphalt mix in environmental perspectives and also in terms of improving the mechanical properties of asphalt mix.

Chapter 5. Conclusions and Recommendations

5.1 Conclusions

Based on experimental work results for WPB modified asphalt mixtures compared with conventional asphalt mixtures, the following conclusions can be drawn:

a) WPB can be conveniently used as a modifier for asphalt mixes for sustainable management of plastic waste as well as for improved performance of asphalt mix.
b) The optimum amount of WPB to be added as a modifier of asphalt mix was found to be (9.0 %) by weight of optimum bitumen content of the asphalt mix.
c) Asphalt mix modified with (9.0 % WPB by OBC weight) has approximately 24% higher stability value compared to the conventional asphalt mix.
d) Asphalt mix modified with WPB exhibit lower bulk density as the WPB percentage increased. This decrease in bulk density can explained to be as a result of the low density of added plastic material.
e) Asphalt mix modified with WPB exhibit higher flow value as the WPB percentage increased. However, the stiffness of the modified mix is increased.
f) There is a slight increase of the cost when using WPB modified asphalt mix compared to conventional asphalt mix. However, this increase of cost can be accepted due to the advantages offered by the modified asphalt mix.

5.2 Recommendations

a) Study recommends local authorities to confirm using WPB in asphalt mix with the proposed percentage (9.0% by OBC weight) for improved performance of asphalt mix.
b) Further studies are needed in various topics related to effective utilization and best incorporation techniques of waste materials in asphalt pavements.
c) Constructing test road sections using WPB modified asphalt mix for further field studies of its performance.
d) Many previous studies show an obvious improvement in rutting resistance for polymer modified asphalt mix. However, related apparatus for testing rutting resistance is not available in Gaza Strip. It's recommended to supply such apparatus for further study in this field.
e) It is recommended to conduct similar studies on the wearing course layer of asphalt pavement.

f) Further studies is recommended for incorporating other waste plastic materials in asphalt mix such as plastics formed from High Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) which widely used in soft drink bottles.

g) Government and researchers should integrate efforts toward preparing and implementing a sustainable solid waste management plan taking into consideration getting the maximum benefit from the high quantities of solid waste.

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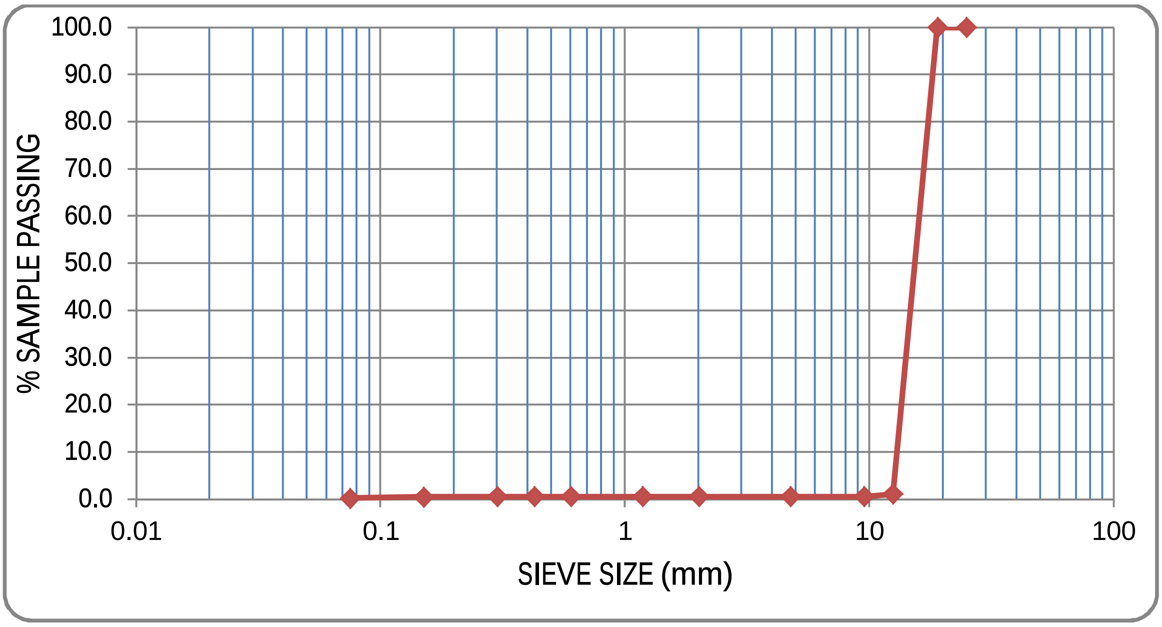
Appendices

Appendix (A)

Aggregates sieve analysis (ASTM C 136)

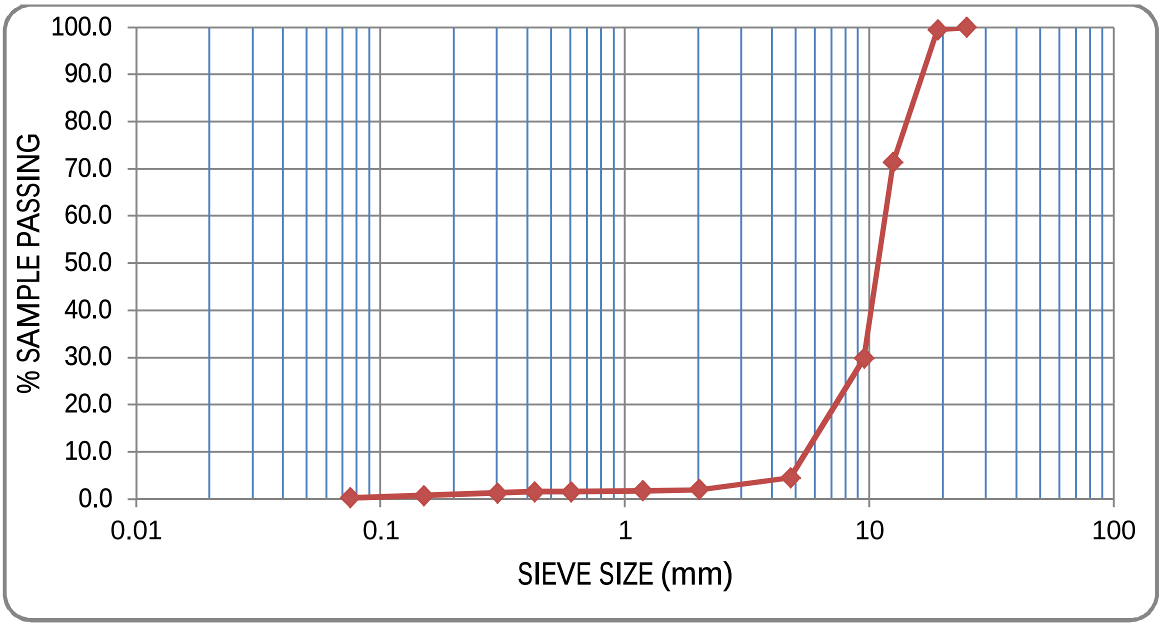
Sieve analysis Folia (0/19)

Sieve size (mm)	Sieve #	Cumulative retained (g)	Cumulative retained (%)	Sample passing (%)
25	1"	0	0.0	100.0
19	3/4"	0	0.0	100.0
12.5	1/2"	1810	98.9	1.1
9.5	3/8"	1820	99.5	0.5
4.75	#4	1820	99.5	0.5
2	#10	1820	99.5	0.5
1.18	#16	1820	99.5	0.5
0.6	#30	1820	99.5	0.5
0.425	#40	1820	99.5	0.5
0.3	#50	1820	99.5	0.5
0.15	#100	1822	99.6	0.4
0.075	#200	1827	99.8	0.2
Pan	Pan	1830	100.0	0.0



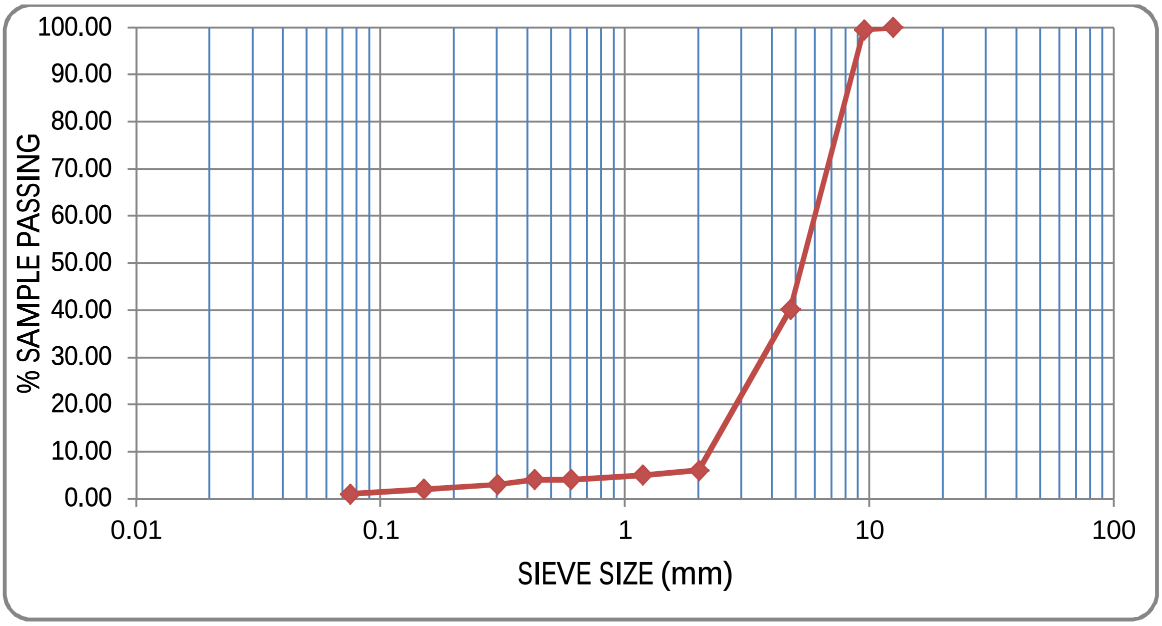
Sieve analysis Adasia (0/12.5)

Sieve size (mm)	Sieve #	Cumulative retained (g)	Cumulative retained (%)	Sample passing (%)
25	1"	0	0.0	100.0
19	3/4"	10	0.5	99.5
12.5	1/2"	570	28.6	71.4
9.5	3/8"	1400	70.2	29.8
4.75	#4	1905	95.5	4.5
2	#10	1955	98.0	2.0
1.18	#16	1960	98.2	1.8
0.6	#30	1965	98.5	1.5
0.425	#40	1965	98.5	1.5
0.3	#50	1970	98.7	1.3
0.15	#100	1980	99.2	0.8
0.075	#200	1990	99.7	0.3
Pan	Pan	1995	100.0	0.0



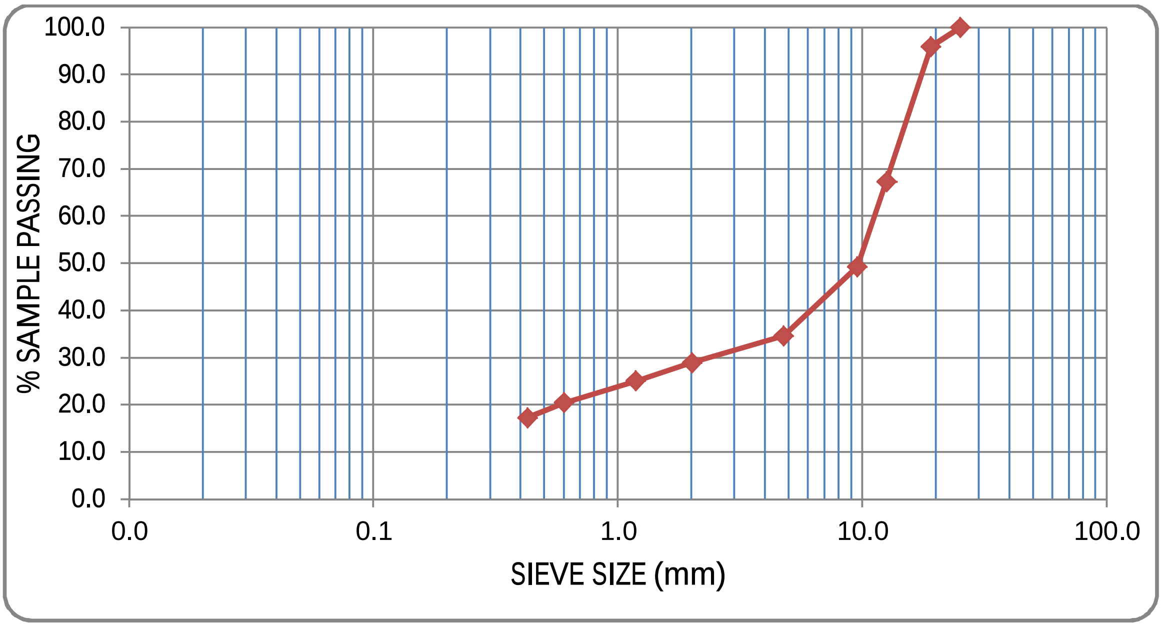
Sieve analysis Simsimia (0/12.5)

Sieve size (mm)	Sieve #	Cumulative retained (g)	Cumulative retained (%)	Sample passing (%)
25	1"	0	0.0	100.00
19	3/4"	0	0.0	100.00
12.5	1/2"	0	0.0	100.00
9.5	3/8"	5	0.5	99.50
4.75	#4	595	59.8	40.20
2	#10	935	94.0	6.03
1.18	#16	945	95.0	5.03
0.6	#30	955	96.0	4.02
0.425	#40	955	96.0	4.02
0.3	#50	965	97.0	3.02
0.15	#100	975	98.0	2.01
0.075	#200	985	99.0	1.01
Pan	Pan	995	100.0	0.00



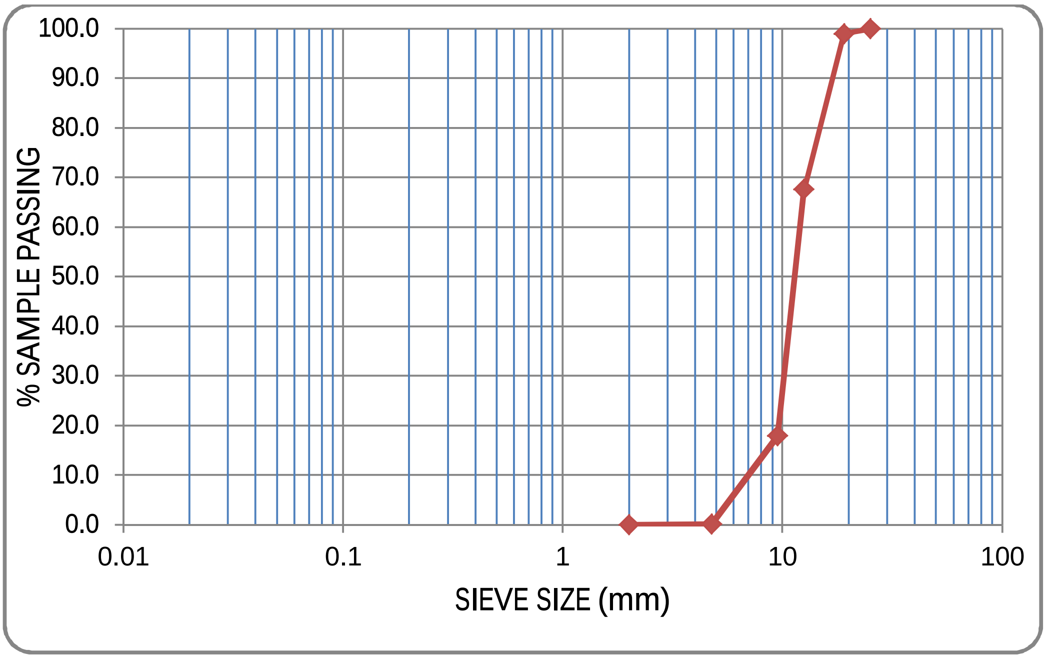
Sieve analysis Trabia (0/4.75)

Sieve size (mm)	Sieve #	Cumulative retained (g)	Cumulative retained (%)	Sample passing (%)
25.0	1"	0.0	0.0	100.0
19.0	3/4"	0.0	0.0	100.0
12.5	1/2"	0.0	0.0	100.0
9.5	3/8"	0.0	0.0	100.0
4.75	#4	28.1	4.0	96.0
2.00	#10	228.7	32.6	67.4
1.180	#16	354.9	50.7	49.3
0.60	#30	457.8	65.4	34.6
0.425	#40	497.5	71.0	29.0
0.300	#50	524.8	74.9	25.1
0.150	#100	557.1	79.5	20.5
0.075	#200	579.4	82.7	17.3
Pan	Pan	700.5	100.0	0.0



Sieve analysis natural sand (0/0.6)

Sieve size (mm)	Sieve #	Cumulative retained (g)	Cumulative retained (%)	Sample passing (%)
25	1"	0.0	0.0	100.0
19	3/4"	0.0	0.0	100.0
12.5	1/2"	0.0	0.0	100.0
9.5	3/8"	0.0	0.0	100.0
4.75	#4	0.0	0.0	100.0
2	#10	0.0	0.0	100.0
1.18	#16	0.0	0.0	100.0
0.6	#30	4.8	1.0	99.0
0.425	#40	162.0	32.4	67.6
0.3	#50	409.8	82.0	18.0
0.15	#100	499.0	99.8	0.2
0.075	#200	499.6	100.0	0.0
Pan	Pan	499.8	100.0	0.0



Appendix (B)

Aggregate Blending

Suggested percentages for binder course aggregate mix

Aggregate mix	Grain size (mm)												Suggested percents for final agg. Mix
	<0.075	0.075/0.15	0.15/0.3	0.3/0.425	0.425/0.6	0.6/1.18	1.18/2.36	2.36/4.75	4.75/9.5	9.5/12.5	12.5/19	19/25	
Filler	61.4	34.6	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Sand (0/0.6)	0.0	0.1	17.8	49.6	31.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0
	0.0	0.0	1.1	3.0	1.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	
Trabia (0/4.75)	17.3	3.2	4.6	3.9	5.7	14.7	18.0	28.6	4.0	0.0	0.0	0.0	34.0
	5.9	1.1	1.6	1.3	1.9	5.0	6.1	9.7	1.4	0.0	0.0	0.0	
Simsimia (0/9.5)	1.0	1.0	1.0	1.0	0.0	1.0	1.0	34.2	59.3	0.5	0.0	0.0	27.0
	0.3	0.3	0.3	0.3	0.0	0.3	0.3	9.2	16.0	0.1	0.0	0.0	
Adasia (0/12.5)	0.3	0.5	0.5	0.3	0.0	0.3	0.3	2.5	25.3	41.6	28.1	0.5	19.0
	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.5	4.8	7.9	5.3	0.1	
Folia (0/19)	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	98.8	0.0	14.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	13.8	0.0	
Sum	6.2	1.5	3.0	4.6	3.8	5.4	6.4	19.4	22.2	8.1	19.2	0.1	100.0
% passing	6.24	7.74	10.75	15.38	19.21	24.59	31.04	50.47	72.65	80.76	99.93	100.00	
Sieve size (mm)	0.075	0.15	0.3	0.425	0.6	1.18	2	4.75	9.5	12.5	19	25	
Binder0/ 19 (min)	2	3	5	6	8	15	23	35	56	67	90	100	ASTM Specifications D5315 – D4
(max)	8	14	19	22	26	37	49	65	80	85	100	100	

Appendix (C)

Calculations of physical properties of aggregates

1. **<u>Specific gravity and absorption</u>** <u>(ASTM C127 - C128)</u>

- **<u>Coarse aggregate (Folia 0/19)</u>**

A= Weight of oven-dry sample in air, grams = 3951.2 gr

B=weight of saturated - surface -dry sample in air = 4045.34 gr

C= weight of saturated sample in water = 2468.13 gr

- Bulk dry S.G = $\frac{A}{B-C} = 2.51$
- SSD S.G = $\frac{B}{B-C} = 2.56$
- Apparent S.G = $\frac{A}{A-C} = 2.66$
- Effective S.G = $\frac{Bulk(dry) + Apparent}{2} = \frac{2.51 + 2.66}{2} = 2.58$
- Absorption = $\frac{(B-A)}{A} * 100 = 2.38\,\%$

- **<u>Coarse aggregate (Adasia 0/12.5)</u>**

  A= Weight of oven-dry sample in air, grams = 3154.8 gr

  B=weight of saturated - surface -dry sample in air = 3233.27 gr

  C= weight of saturated sample in water = 1965.03 gr

i. Bulk dry S.G = $\frac{A}{B-C} = 2.49$

ii. SSD S.G = $\frac{B}{B-C} = 2.55$

iii. Apparent S.G = $\frac{A}{A-C} = 2.65$

iv. Effective S.G = $\frac{Bulk(dry) + Apparent}{2} = \frac{2.49 + 2.65}{2} = 2.57$

v. Absorption $= \frac{(B-A)}{A} * 100 = 2.49\,\%$

- **<u>Coarse Aggregate (Simsimia 0/9.5)</u>**

A= Weight of oven-dry sample in air, grams = 1014.1gr

B=weight of saturated - surface -dry sample in air = 1042.35 gr

C= weight of saturated sample in water = 642.86 gr

i. Bulk dry S.G $= \frac{A}{B-C} = 2.54$

ii. SSD S.G $= \frac{B}{B-C} = 2.61$

iii. Apparent S.G $= \frac{A}{A-C} = 2.73$

iv. Effective S.G = $\frac{Bulk(dry) + Apparent}{2} = \frac{2.54 + 2.73}{2} = 2.64$

v. Absorption $= \frac{(B-A)}{A} * 100 = 2.79\,\%$

2. <u>Abrasion value (ASTM C131)</u>

Grade (B)

Passing 19mm (3/4”) Retained on 12.5 mm (1/2”) = 2500 gr

Passing 12.5mm (1/2”) Retained on 9.5mm (3/8”) = 2500 gr

A= Original sample weight = 5000 gr

B=Weight retained on the 1.7mm sieve = 3880 gr

A.V $= \frac{A-B}{A} * 100 = 22.4\%$

Appendix (D)

Binder Course Job Mix

Used Equations to calculate the mechanical properties of asphalt mix

$$V_a = \frac{r_{bit} - r_A}{r_{bit}} \times 100\%.$$

$$V_b = m_b \times \frac{r_A}{d_{25}} \%.$$

$$\%VMA = V_a + V_b.$$

$$\%VFB = \frac{V_b.}{VMA} \times 100\,.$$

V_b : Percent bitumen volume.

V_a : Air voids contents in total mix.

m_b : Percent of Bitumen.

r_A : Density of compacted mix (g/cm^3).

d_{25} : Density of Bitumen at 25^{o}C.

r_{bit} : Max. Theoretical density.

VMA : Voids in mineral Aggregates.

VFB : Voids filled with bitumen

Marshal tests results

Bitumen content = 4.0 %

- No. of blows on each side : 75 blow
- Mixing temp. : 150 C

Bitumen % (By total weight)	4 %			
Sample No.	**1**	**2**	**3**	**Average**
Weight of sample in air (g)	1209.14	1208.07	1211.51	1209.57
Weight in water (gm)	692.2	685.7	696.5	691.47
SSD weight (gm)	1214.84	1214.61	1219.25	1216.23
Bulk volume (cm3)	522.64	528.91	522.75	524.77
Density of compacted mix ρA (g/cm3)	2.31	2.28	2.32	2.31
Max. theoretical density ρbit (g/cm3)	2.50	2.50	2.50	2.50
Average sample hight (mm)	66.3	67.7	66.7	66.9
Stability read value	1314	1263	1210	1262.33
Stability (Kg)	1629.36	1566.12	1500.4	1565.29
Stability correction factor	0.9314	0.902	0.9226	0.919
Corrected stability (Kg)	1517.59	1412.64	1384.27	1438.17
Flow (mm)	3.37	3.13	2.47	2.99
Stiffness (Kg/mm)	450.58	451.15	559.75	480.87
Air voids content in total mix Va (%)	7.46	8.64	7.30	7.80
Percent bitumen volume Vb (%)	9.03	8.91	9.04	9.00
Voids in mineral Agg. (VMA) (%)	16.49	17.55	16.34	16.79
Voids fill with bitumen (VFB) (%)	54.76	50.79	55.35	53.63

Marshal tests results

Bitumen content = 4.5 %

- No. of blows on each side : 75 blow
- Mixing temp. : 150 C

Bitumen % (By total weight)	4.5 %			
Sample No.	1	2	3	Average
Weight of sample in air (g)	1203.47	1212.18	1202.77	1206.14
Weight in water (gm)	694.71	694.91	690.9	693.51
SSD weight (gm)	1208.04	1216.73	1205.66	1210.14
Bulk volume (cm3)	513.33	521.82	514.76	516.64
Density of compacted mix ρA (g/cm3)	2.34	2.32	2.34	2.33
Max. theoretical density ρbit (g/cm3)	2.48	2.48	2.48	2.48
Average sample hight (mm)	65.3	66.0	65.0	65.4
Stability read value	1310	1190	1210	1236.67
Stability (Kg)	1624.4	1475.6	1500.4	1533.47
Stability correction factor	0.9548	0.938	0.962	0.952
Corrected stability (Kg)	1550.98	1384.11	1443.38	1459.49
Flow (mm)	3.58	2.87	2.52	2.99
Stiffness (Kg/mm)	432.78	481.60	571.91	487.50
Air voids content in total mix Va (%)	5.52	6.38	5.83	5.91
Percent bitumen volume Vb (%)	9.15	9.07	9.12	9.11
Voids in mineral Agg. (VMA) (%)	14.67	15.45	14.95	15.02
Voids fill with bitumen (VFB) (%)	62.38	58.69	60.98	60.69

Marshal tests results

Bitumen content = 5 %

- No. of blows on each side : 75 blow
- Mixing temp. : 150 C

Bitumen % (By total weight)	5 %			
Sample No.	1	2	3	Average
Weight of sample in air (g)	1214.31	1219.87	1199.10	1211.09
Weight in water (gm)	703.1	702.14	691.17	698.80
SSD weight (gm)	1218.82	1222.32	1200.29	1213.81
Bulk volume (cm3)	515.72	520.18	509.12	515.01
Density of compacted mix ρA (g/cm3)	2.35	2.35	2.36	2.35
Max. theoretical density ρbit (g/cm3)	2.46	2.46	2.46	2.46
Average sample hight (mm)	66.0	66.3	64.7	65.7
Stability read value	1243	1312	1274	1276.33
Stability (Kg)	1541.32	1626.88	1579.76	1582.65
Stability correction factor	0.938	0.9314	0.9695	0.946
Corrected stability (Kg)	1445.76	1515.28	1531.58	1497.54
Flow (mm)	2.99	3.34	3.13	3.15
Stiffness (Kg/mm)	483.48	453.04	489.53	474.72
Air voids content in total mix Va (%)	4.40	4.78	4.37	4.52
Percent bitumen volume Vb (%)	9.19	9.15	9.19	9.18
Voids in mineral Agg. (VMA) (%)	13.59	13.94	13.56	13.70
Voids fill with bitumen (VFB) (%)	67.62	65.67	67.76	67.02

Marshal tests results

Bitumen content = 5.5 %

- No. of blows on each side : 75 blow
- Mixing temp. : 150 C

Bitumen % (By total weight)	5.5 %			
Sample No.	1	2	3	Average
Weight of sample in air (g)	1223.80	1198.31	1200.15	1207.42
Weight in water (gm)	704.46	691.25	688.12	694.61
SSD weight (gm)	1226	1199.65	1202.32	1209.32
Bulk volume (cm3)	521.54	508.4	514.2	514.71
Density of compacted mix ρA (g/cm3)	2.35	2.36	2.33	2.35
Max. theoretical density ρbit (g/cm3)	2.44	2.44	2.44	2.44
Average sample hight (mm)	65.7	63.9	64.7	64.8
Stability read value	1372	1105	1046	1174.33
Stability (Kg)	1701.28	1370.2	1297.04	1456.17
Stability correction factor	0.9452	0.9896	0.9695	0.968
Corrected stability (Kg)	1608.05	1355.95	1257.48	1407.16
Flow (mm)	3.50	3.39	2.83	3.24
Stiffness (Kg/mm)	459.92	399.89	444.07	434.36
Air voids content in total mix Va (%)	4.02	3.59	4.53	4.05
Percent bitumen volume Vb (%)	9.16	9.20	9.11	9.15
Voids in mineral Agg. (VMA) (%)	13.18	12.79	13.64	13.20
Voids fill with bitumen (VFB) (%)	69.49	71.92	66.77	69.39

Marshal tests results

Bitumen content = 6 %

- No. of blows on each side : 75 blow
- Mixing temp. : 150 C

Bitumen % (By total weight)	6 %			
Sample No.	1	2	3	Average
Weight of sample in air (g)	1197.17	1199.55	1203.64	1200.12
Weight in water (gm)	685.1	686.8	688.18	686.69
SSD weight (gm)	1198.13	1200.34	1204.73	1201.07
Bulk volume (cm3)	513.03	513.54	516.55	514.37
Density of compacted mix ρA (g/cm3)	2.33	2.34	2.33	2.33
Max. theoretical density ρbit (g/cm3)	2.43	2.43	2.43	2.43
Average sample hight (mm)	63.3	64.0	64.4	63.9
Stability read value	1245	1103	1062	1136.67
Stability (Kg)	1543.8	1367.72	1316.88	1409.47
Stability correction factor	1.0052	0.987	0.977	0.990
Corrected stability (Kg)	1551.83	1349.94	1286.59	1396.12
Flow (mm)	4.26	4.08	4.21	4.18
Stiffness (Kg/mm)	364.42	330.98	305.41	333.74
Air voids content in total mix Va (%)	3.85	3.76	3.99	3.87
Percent bitumen volume Vb (%)	9.11	9.12	9.09	9.11
Voids in mineral Agg. (VMA) (%)	12.96	12.87	13.08	12.97
Voids fill with bitumen (VFB) (%)	70.28	70.82	69.50	70.20

Determination of the theoretical maximum density for the asphalt mix

It is known that calculating the theoretical asphalt mix density can be done by using the Pycnometer or by calculations using specific gravities for all aggregates.

Calculation method:

$$r_{min} = \frac{100}{\frac{m_1}{r\ min_1} + \frac{m_2}{r_{min\,2}} + \frac{m_3}{r_{min\,3}} + \frac{m_4}{r_{min\,4}}}$$

$$r_{bit} = \frac{100}{\frac{m_b}{d_{25}} + \frac{100 - m_b}{r_{min}}}$$

r_{bit} : Max. Theoretical density.

m_b : % of bitumen by total mix.

d_{25} : Density of bitumen.

m_1 : The percentage of aggregate type (1) in the aggregates blend.

$r\ min_1$: Density of aggregate type (1).

Determination of the maximum theoretical density for the asphalt mix

Aggregate type	Percentage in aggregate mix m %	Aggregate density ρ_{min} (g/cm^3)	m / ρ_{min}
Folia	14.0	2.58	12.32
Adasia	19.0	2.57	2.26
Simsimia	27.0	2.64	10.23
Trabiah	34.0	2.76	7.39
Sand	6.0	2.65	5.43
		Sum	37.63

- Effective Specific gravity for aggregate mix ρ_{min} = 100 / 37.63 = 2.66 (g/cm^3)

Bitumen percentage *mb* %	Bitumen density d_{25} (g/cm^3)	Aggregate blend density ρ_{min} (g/cm^3)	Max. Theoretical density r_{bit} (g/cm^3)
4	1.023	2.66	2.50
4.5	1.023	2.66	2.48
5	1.023	2.66	2.46
5.5	1.023	2.66	2.44
6	1.023	2.66	2.43

Example: r_{bit} for 5% bitumen

$$r_{bit} = \frac{100}{\frac{mb}{1.023} + \frac{100-5}{2.66}} = 2.46\ g/cm^3$$

Appendix (E)

WPB Modified asphalt mix tests results

Marshal tests results

Conventional mix

WPB = 0 %

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	0 %			
Sample No.	1	2	3	Average
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1202.70	1185.21	1194.61	1194.17
Weight in water (g)	695.6	682.59	690.5	689.56
SSD weight (g)	1203.82	1187.4	1195.7	1195.64
Bulk volume (cm3)	508.22	504.81	505.2	506.08
Density of compacted mix ρA (g/cm^3)	2.37	2.35	2.36	2.36
Max. theoretical density ρbit (g/cm^3)	2.46	2.46	2.46	2.46
Average sample hight (mm)	64.0	64.0	63.7	63.9
Stability read value	1233	1305	1273	1270.3
Stability (Kg)	1528.92	1550.12	1535.64	1538.23
Stability correction factor	0.987	0.987	0.9948	0.990
Corrected stability (Kg)	1509.04	1529.97	1527.65	1522.222
Flow (mm)	2.89	2.93	3.08	2.97
Stiffness (Kg/mm)	528.99	529.35	498.77	519.04
Air voids content in total mix Va (%)	3.87	4.63	3.94	4.15
Percent bitumen volume Vb (%)	11.80	11.70	11.79	11.76
Voids in mineral Agg. (VMA) (%)	15.66	16.33	15.73	15.91
Voids fill with bitumen (VFB) (%)	75.31	71.68	74.94	73.97

Marshal tests results

WPB = 6 % (By OBC weight)

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	6 %			
Sample No.	1	2	3	Average
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1195.22	1196.57	1199.18	1196.99
Weight in water (g)	687	686.82	693.2	689.01
SSD weight (g)	1196.55	1198.56	1200.63	1198.58
Bulk volume (cm3)	509.55	511.74	507.43	509.57
Density of compacted mix ρA (g/cm^3)	2.35	2.34	2.36	2.35
Max. theoretical density ρbit (g/cm^3)	2.46	2.46	2.46	2.46
Average sample hight (mm)	63.5	64.2	63.4	63.7
Stability read value	1365	1360	1555	1426.67
Stability (Kg)	1692.6	1686.4	1928.2	1769.07
Stability correction factor	1	0.982	1.0026	0.995
Corrected stability (Kg)	1692.60	1656.04	1933.21	1760.619
Flow (mm)	3.11	2.58	3.24	2.97
Stiffness (Kg/mm)	545.05	654.40	595.65	598.37
Air voids content in total mix Va (%)	4.46	4.77	3.75	4.33
Percent bitumen volume Vb (%)	11.69	11.66	11.78	11.71
Voids in mineral Agg. (VMA) (%)	16.16	16.42	15.53	16.04
Voids fill with bitumen (VFB) (%)	72.37	70.98	75.87	73.07

Marshal tests results

WPB = 8 % (By OBC weight)

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	8 %			
Sample No.	1	2	3	Average
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1200.93	1198.95	1205.37	1201.75
Weight in water (g)	688.03	685.55	693.38	688.99
SSD weight (g)	1201.65	1199.32	1206.85	1202.61
Bulk volume (cm3)	513.62	513.77	513.47	513.62
Density of compacted mix ρA (g/cm^3)	2.34	2.33	2.35	2.34
Max. theoretical density ρbit (g/cm^3)	2.448	2.448	2.448	2.448
Average sample hight (mm)	63.8	64.5	64.6	64.3
Stability read value	1546	1524	1291	1453.67
Stability (Kg)	1917.04	1889.76	1600.84	1802.55
Stability correction factor	0.9922	0.9745	0.972	0.980
Corrected stability (Kg)	1902.09	1841.57	1556.02	1766.558
Flow (mm)	3.35	3.11	2.88	3.11
Stiffness (Kg/mm)	572.64	608.17	555.26	578.69
Air voids content in total mix Va (%)	4.47	4.65	4.09	4.40
Percent bitumen volume Vb (%)	11.66	11.63	11.70	11.66
Voids in mineral Agg. (VMA) (%)	16.12	16.29	15.79	16.07
Voids fill with bitumen (VFB) (%)	72.29	71.43	74.12	72.62

Marshal stability and flow test

WPB = 10 % (By OBC weight)

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	10 %			
Sample No.	**1**	**2**	**3**	**Average**
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1198.46	1190.77	1198.58	1195.94
Weight in water (g)	688.7	686.03	691.32	688.68
SSD weight (g)	1199.81	1192.83	1201.79	1198.14
Bulk volume (cm3)	511.11	506.8	510.47	509.46
Density of compacted mix ρA (g/cm^3)	2.34	2.35	2.35	2.35
Max. theoretical density ρbit (g/cm^3)	2.454	2.454	2.454	2.454
Average sample hight (mm)	63.3	63.1	64.0	63.5
Stability read value	1612.00	1653.00	1504.00	1589.67
Stability (Kg)	1998.88	2049.72	1864.96	1971.19
Stability correction factor	1.0052	1.0104	0.987	1.001
Corrected stability (Kg)	2009.27	2071.04	1840.72	1973.676
Flow (mm)	2.83	3.14	3.68	3.22
Stiffness (Kg/mm)	705.57	652.96	507.11	621.88
Air voids content in total mix Va (%)	4.46	4.26	4.33	4.35
Percent bitumen volume Vb (%)	11.69	11.71	11.71	11.70
Voids in mineral Agg. (VMA) (%)	16.15	15.98	16.03	16.05
Voids fill with bitumen (VFB) (%)	72.39	73.31	73.00	72.90

Marshal stability and flow test

WPB = 12 % (By OBC weight)

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	12 %			
Sample No.	1	2	3	Average
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1198.17	1204.14	1197.28	1199.86
Weight in water (g)	689.4	694.48	685.29	689.72
SSD weight (g)	1199.56	1206.26	1199.51	1201.78
Bulk volume (cm3)	510.16	511.78	514.22	512.05
Density of compacted mix ρA (g/cm^3)	2.35	2.35	2.33	2.34
Max. theoretical density ρbit (g/cm^3)	2.455	2.455	2.455	2.455
Average sample hight (mm)	63.6	64.2	64.1	63.9
Stability read value	1548	1592	1722	1620.67
Stability (Kg)	1919.52	1974.08	2135.28	2009.63
Stability correction factor	0.9974	0.982	0.9845	0.988
Corrected stability (Kg)	1914.53	1938.55	2102.18	1985.086
Flow (mm)	3.21	3.59	3.71	3.50
Stiffness (Kg/mm)	597.93	549.94	576.30	574.73
Air voids content in total mix Va (%)	4.32	4.14	5.14	4.53
Percent bitumen volume Vb (%)	11.71	11.73	11.61	11.68
Voids in mineral Agg. (VMA) (%)	16.02	15.87	16.75	16.22
Voids fill with bitumen (VFB) (%)	73.07	73.89	69.30	72.09

Marshal stability and flow test

WPB = 14 % (By OBC weight)

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	14 %			
Sample No.	1	2	3	Average
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1212.79	1199.78	1208.90	1207.16
Weight in water (g)	695.51	689.21	694.35	693.02
SSD weight (g)	1214.54	1201.24	1210.32	1208.70
Bulk volume (cm3)	519.03	512.03	515.97	515.68
Density of compacted mix ρA (g/cm^3)	2.34	2.34	2.34	2.341
Max. theoretical density ρbit (g/cm^3)	2.458	2.458	2.458	2.458
Average sample hight (mm)	64.6	63.4	63.5	63.8
Stability read value	1647	1662	1651	1653.33
Stability (Kg)	2042.28	2060.88	2047.24	2050.13
Stability correction factor	0.972	1.0026	1	0.992
Corrected stability (Kg)	1985.10	2066.24	2047.24	2032.858
Flow (mm)	3.28	3.21	3.72	3.40
Stiffness (Kg/mm)	622.53	641.06	550.80	604.80
Air voids content in total mix Va (%)	4.94	4.67	4.68	4.76
Percent bitumen volume Vb (%)	11.65	11.68	11.68	11.67
Voids in mineral Agg. (VMA) (%)	16.59	16.35	16.36	16.43
Voids fill with bitumen (VFB) (%)	70.23	71.43	71.39	71.02

Marshal stability and flow test

WPB = 16 % (By OBC weight)

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	16 %			
Sample No.	1	2	3	Average
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1200.80	1197.52	1195.07	1197.80
Weight in water (g)	684.36	679.72	681.3	681.79
SSD weight (g)	1202.18	1198.41	1196.27	1198.95
Bulk volume (cm3)	517.82	518.69	514.97	517.16
Density of compacted mix ρA (g/cm^3)	2.32	2.31	2.32	2.32
Max. theoretical density ρbit (g/cm^3)	2.431	2.431	2.431	2.431
Average sample hight (mm)	64.6	64.7	64.3	64.5
Stability read value	1598	1712	1489	1599.67
Stability (Kg)	1981.52	2122.88	1846.36	1983.59
Stability correction factor	0.972	0.9695	0.9795	0.974
Corrected stability (Kg)	1926.04	2058.13	1808.51	1930.893
Flow (mm)	3.99	4.27	3.38	3.88
Stiffness (Kg/mm)	496.62	497.69	546.37	513.56
Air voids content in total mix Va (%)	4.61	5.03	4.54	4.72
Percent bitumen volume Vb (%)	11.56	11.51	11.57	11.55
Voids in mineral Agg. (VMA) (%)	16.17	16.54	16.11	16.27
Voids fill with bitumen (VFB) (%)	71.51	69.60	71.83	70.98

Marshal stability and flow test

WPB = 18 % (By OBC weight)

- No. of blows on each side : 75 blow
- 3/4" binder course mix
- Bitumen = 5.1 % (By total weight)
- Mixing temp. : 150 C

WPB content (By OBC Weight)	18 %			
Sample No.	1	2	3	Average
Bitumen % (By total weight)	5.1	5.1	5.1	5.1
Weight of sample in air (g)	1192.40	1199.68	1199.37	1197.15
Weight in water (g)	680.55	681.67	681.47	681.23
SSD weight (g)	1193.34	1200.7	1200.56	1198.20
Bulk volume (cm3)	512.79	519.03	519.09	516.97
Density of compacted mix ρA (g/cm^3)	2.33	2.31	2.31	2.32
Max. theoretical density ρbit (g/cm^3)	2.434	2.434	2.434	2.434
Average sample hight (mm)	63.6	64.7	64.7	64.4
Stability read value	1515	1375	1377	1422.33
Stability (Kg)	1878.6	1705	1707.48	1763.69
Stability correction factor	0.9974	0.9695	0.9695	0.979
Corrected stability (Kg)	1873.72	1653.00	1655.40	1727.37
Flow (mm)	3.72	3.28	5.11	4.04
Stiffness (Kg/mm)	505.35	519.55	334.25	453.05
Air voids content in total mix Va (%)	4.46	5.03	5.06	4.85
Percent bitumen volume Vb (%)	11.59	11.52	11.52	11.54
Voids in mineral Agg. (VMA) (%)	16.05	16.55	16.58	16.39
Voids fill with bitumen (VFB) (%)	72.24	69.62	69.46	70.44

Determination of the maximum theoretical density for the asphalt mix

Pycnometer method

(W_{P+W}) = Weight of Pycnometer filled with water

(W_s) = Weight of the asphalt sample

(W_{s+P+W}) = Weight of Pycnometer filled with water and the crushed sample

$$r_{bit} = \frac{W_s}{W_s - (W_{s+p+w} - W_{p+w})}$$

WPB % (by OBC weight)	W_{P+W} (g)	W_s (g)	W_{s+P+W} (g)	ρ_{bit} (g/cm^3)
0	1784.26	415.46	2030.95	2.462
6	1784.26	410.64	2027.65	2.455
8	1784.26	410.74	2027.18	2.448
10	1784.26	410.42	2027.45	2.454
12	1784.26	405.15	2024.35	2.455
14	1784.26	410.44	2027.72	2.458
16	1784.26	415.3	2028.72	2.431
18	1784.26	410.21	2025.92	2.434

Appendix (F)

Photos

Figure (F.1): *Trabia (0/4.75) source (Al-Amal Factory)*

Figure (F.2): *Used waste plastic source*

Figure (F.3): *Waste plastic grinding*

Figure (F.4): *Aggregates preparing for specific gravity and water absorption t*

Figure (F.5): *Job mix Marshal Samples*

Figure (F.6): *Marshal Samples weighting in water*

Figure (F.2): *Water bath for Marshal Samples*

Figure (F.8): *Adding WPB to the Aggregates*

Figure (F.9): *Removing Marshal samples molds after compaction*

Figure (F.10): *WPB modified Marshal Samples*

Figure (F.11): *Testing Marshal Samples for stability and flow*

Figure (F.12): *Measuring the theoretical density of asphalt mix using Pycnometer*