PEPOLE S DEMOCRATIC REPUBLIC OF ALGERIA

Ministire of Higher Education and Scientifics Research

Kasdi Merbah University of Ouargla

Faculty Of Applied Sciences

C:..........

R:..........

Department of Civil Engineering and hydraulic

End of study memory for obtaining the master s degree

Specialty: Pavement and Art Construction

Submitted by :BENSGHIER Rym

Theme

Characteristics of Polymer Modified Asphalt Concrete : a Hot Mixture Asphalt (HMA) class 0/14

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Academic year : 2019 / 2020

ACKNOWLEDGEMENT

First of all, all thanks go to the Almighty ***Allah****, who gave me the strength and faith to write this thesis despite the hardships I faced. Without Allah's mercy I would never accomplish this humble work.*

This dissertation would have never been accomplished without the help and patience of my supervisor Mr.BOUCHERBA Mohammed who devoted his precious time and being patient throughout this long journey and guiding me to complete this research.

My sincere thanks also goes to my uncle Dr. BENAISSA Hocine, for his precious help.

I also express my gratitude and deep appreciation to the members of the jury who discussed and examined this dissertation. I thank them for their contribution and their support especially in this fatal year.

Finally, I would like to present all my gratitude and respect to all my friends and colleagues who were always friendly and cooperate.

Dedication

I dedicate this work to my loving parents, Mohammed Salah and Rahima, who's the source of my power and courage to become what i am now, I will always appreciate their unconditional support.

Special feeling of gratitude to my strength wall my three brothers; ABDERRAHMANE, OUSSAMA and AYMEN, to my heart IMANE, for their encouragement and help, thanks for being by my side.

To my life mates and especially in this journey, a big thank for, Yassmine; Aya; Yassmina.

Also I would like to thank my dearest friends, BENOUANE Maroua and LICHANI Rachaa.

A special thanks goes to my classmates for their help and encouragement.

Thank you all for being parts of this work.

SUMMARY

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ε	*The strain*
$\sigma 0$	*the peak stress amplitude*
d	*Aggregate Lower Diameter in mm*
D	*Aggregate upper Diameter in mm*
G	*The proportion of aggregate particles grates than 6.3mm*
S	*The proportion of aggregate particles include between 6.3mm and 0.135mm*
s	*The proportion of aggregate particles between 0.135mm and 0.063mm*
f	*The proportion of aggregate particles less than 0.063mm*
Σ	*The Specific Surface Area, in m2/kg*
α	*Correction coefficient relative to the density of aggregates*
HMA	*Hot Mix Asphalt*
TL	*Binder content*
PMB	*Polymer Modified bitumen*
PB	*Pure Bitumen*
η	*viscosity*

INTRODUCTION

The roads is one of the transportation tools, cover an economic part during goods transportation, also a tourist and traveling, and every day use. So, the user expect better and high performance from asphalt pavement, including higher standards of safety, economic and comfortability, that's why the industry field knows a develop in the last 70 years, some of this technics of development the modifying bitumen by adding additive mineral or organic among this additive a wide one was swept the industry. Today, Algeria start produce their own modified bitumen thanks to "NAFTAL, and this modification base of the polymer that have the same petroleum-based as bitumen, in order to improve their properties and rheological behaviour to support this growth in traffic and heavy goods vehicles, also the climatic changes, and the traffic rise Algeria has been known for in this last years.

In order to conserve the condition of good use and durability, an adhesive and mechanical properties in the road pavements, have to measure the chosen material used specially bitumen, who has play a large role in determining many aspects in road performance and with the development.

A several researches and studies was directed to this purpose, specially for the asphalt and asphalt mix behaviour to improve their thermal and mechanical characteristics, which allow to formulate an effective bituminous mix for long –term resistance.

In our study, basing in the improvement shown in the modified bitumen from the previous researches that has been answered to the main question, what is the situation of Algerian polymer modified bitumen? and does it answer the difference requirement which impact positively on the roads in future?

To answer this question, we present this research project, where we used the Algerian BMP to produce an asphalt mixture and measure theirs physical and mechanical performances, to present our work, this report goes throw six chapter as the following:

- **First chapter:** Generality on Asphalt Concrete, it is a look throw the composition and the relevance test of each composite.
- **Second chapter:** Generality on Bitumen, to know all about bitumen including definition, composition, fabrication and behaviour.
- **Third chapter:** Modification of Bitumen, this chapter touching the objective from the modification, the process, the additive used (polymer) and the changes comes with this modification in structure and behaviour.
- **Fourth chapter:** Material Characteristics, it presents the different used material of the asphalt mix and their properties.
- **Fifth chapter:** The Mixture Formula**,** it shows the way to get an asphalt concrete.
- **Sixth chapter:** Performance and results include the comparison between asphalt concrete based on modified bitumen and asphalt concrete based on pure bitumen.

I. GENERALITIES ON ASPHALT CONCRETE

I. GENERALITIES ON ASPHALT CONCRETE:

I.1.INTRODUCTION

We present a generality about asphalt concrete, and its components and their appropriate characteristics.

Then, the survey of asphalts formulations, considering the following parameter: aggregates size, binder hardness, binder content...etc. Each one has a specific behavior which impact on the compactness, implementation, stiffness and durability ... etc., as well as the main characterizations test according to the standards of obtain a mix according to the desired choice.

I.2.DEFINITION OF ASPHALT CONCRETE

Asphalt concrete is a composite material consisting of a mixture of granular (gravel, sand, fines) and a hydrocarbon binder (bitumen, possibly additives); the aggregates ensure the rigid structure of the asphalt and the bitumen provides cohesion and is responsible for the viscous character[1]. Each of these two components are defined by their rheological and mechanical characteristics. Knowing these characteristics makes it possible to obtain a good performance of the bituminous mixture [1].

I.2.1. Hydrocarbon binders

Hydrocarbon binders play an important role in modern road technology; it has been known and used for a long time, the adhesion and impermeability properties of natural bitumen and asphalt have been known since the emergence of civilization [1]. The word "binder" can be defined as a substance that serves to bring together in a sustainable manner, generally solid particles; the adjective "hydrocarbon" refers to the assembly of carbon atoms and hydrogen [1]. The substance added to the solid particles develops adhesion and cohesion forces within a mixture, ensuring a certain rigidity and resistance to tensile deformation, compressive resistance and shear strength [1]. The hydrocarbon binders can be divided into three types: natural binders, tars and bitumen.

a) Natural binders

They can find in the natural state like natural bitumen or asphalt rock, often in combination with mineral materials. And they have been known and used since very ancient times [1].

b) Tars

Tars produced by the pyrogenic of vegetable materials such as lignite, peat or wood in an air-free environment. Coal is the main source; in which case the correct term to apply is "coal tar" [2].

c) Bitumen

Petroleum Bitumen, normally called “Bitumen” or “Asphalt” is produced by refining crude oil, and used as a binder in road-building products, it is a very viscous, black or dark brown material. The crude oil is pumped from storage tanks, where it is kept at about 60°C, through a heat exchanger system where its temperature is increased [3].

When applying heat on bitumen it is viscous, but it turns solid once it cools down. Therefore, Bitumen operates as the binder/glue for pieces of the aggregate [3].

I.2.2. Aggregates

Aggregate is a collective term for the mineral materials such as sand, gravel and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as asphalt concrete and Portland cement concrete) [4].

I.2.3. The roles of aggregates in asphalt

An aggregate’s mineral composition largely determines the physical characteristics, and how it behaves as a pavement material. Therefore, when selecting an aggregate source, knowledge of the quarry rock’s mineral properties can provide an excellent clue as to the suitability of the resulting aggregate [4]. Aggregate surface chemistry can determine how well an asphalt binder will adhere to an aggregate surface. Poor adherence, commonly referred to as stripping, this can affect the workability and the performance of bituminous mixtures [4]. Depending on the traffic number, the pavement can become slippery. This aspect is the subject of laboratory and road research to determine the surface textures and mineralogical compositions of granular materials in order to obtain rough bituminous mixtures that meet the required conditions. The aggregates used in the production of bituminous asphalt mixes must therefore meet quality criteria and characteristics specific to each use [1].

I.2.4. Aggregate classification

Aggregates are classified into different aggregate classes according to the size of the elements. Designation of aggregate in terms of lower diameter “d” and upper diameter “D” sieve sizes expressed as “d/D”, the size is expressed in millimeters. It is accepted that an Aggregates reaction may contain up to 15% higher excess materials [5].

The following granular classes can be distinguished:

Fines 0/D	with	$D \leq 0{,}080$ m
Sands 0/D	with	$D \leq 6{,}3$mm
Coarse d/D	with	$d \geq 2$ mm et $D \leq 31{,}5$ mm
Gravel 0/D	with	$6{,}3\text{mm} < D \leq 80$ mm
Gravel 0/D	with	$6{,}3\text{mm} < D \leq 80$ mm

Fillers is the particle size fraction of an aggregate, which passes the 0,063 mm sieve. [5].

The mixture of the filler with the binder is the parameter that gives the asphalt its stability, and the thickness of the mixture film is characterized by a criterion called the richness modulus. The cleanliness of the filler, in particular its low clay content, is essential to ensure good mechanical performance.

I.3.CLASSIFICATION OF ASPHALT MIXES

Asphalt mixes are materials resulting from a mixture of aggregates and a hydrocarbon binder. The binder-aggregate mixture obtained consists of three phases [4]:

• The solid phase: represented by the granular skeleton;

• The viscous phase: represented by the contribution of the binder that ensures cohesion;

• The gas phase: represented by the percentage of air voids contained in the mixture.

The changes had in the techniques of both civil engineering and industry have led to the development of different types of asphalt mixes, each of which must meet precise specifications [6]. Types of mixtures for asphalt concretes AC according to NF EN 13108-1:

• AC-BBSG (Asphalt concrete for surface and binder course)

• AC-BBME (High modulus Asphalt concrete for surface and binder course)

• AC-BBM (Thin layer Asphalt concrete)

• AC-BBA (Asphalt concrete for surface and binder course for airfield)

• AC-GB (Graves-Bitumen),

• AC-EME (High modulus Asphalt concrete for base course).

And in the same way, for the other types of materials:

• BBTM (very thin layer asphalt concrete),

• PA-BBDr (Porous Asphalt – Béton Bitumineux Drainant).

I.4. CHARACTERISTICS OF AGGREGATE

The properties of aggregates used in Hot Mixture Asphalt (HMA) are very important to the performance of HMA in pavements. Many of the current aggregate test methods were developed to empirically characterize aggregates [7].

I.4.1. Tests for Geometrical Properties of Aggregates (NF EN 933)

- o Sieve analysis
- o Flakiness index

I.4.2. Tests for Mechanical and Physical Properties of Aggregates (NF EN 1097)

- Resistance to attrition (micro-Deval)
- Resistance to fragmentation (Los Angeles)
- Bleu Methylene test
- Sand equivalent test

I.5. CHARACTERISTICS OF BITUMEN BINDER

Bitumen act as glue that hold the aggregate toghter, that since called bitumen binder, to ensure it stand against the separation of the mixture. We do several tests that determinate the characteristics of pure bitumen and bituminous binder according to standards.

- Penetration test at 25º [NF EN 14 26]
- Softening point (Ring and Ball) (ºC) [NF EN 14 27]

II. GENERALITY ON BITUMEN

II. GENERALITY ON BITUMEN

II.1. INTRODUCTION

Bitumen has been used for century, cause of his exisistance in nature around the world. The first used of bitumen was in the Eaphrates valley in Mesopotamia modern Iraq (Now) in his naturel state (pure bitumen), but the use of bitumen in road construction appeared in Europe in 1830s exact in France and England, since then becomes wildly use for pavement and roofs, which has improved in 1870s in USA. , despite his different names, in North America "Asphalt" means " bitume ", and the word" bitumen" referencing to bitumen fraction. In the other European country bitume referencing to the petroleum product. But the same purpose and aim of use [8].

II.2. DIFINITION OF BITUMEN

Bitumen is a mixture of organic liquids that are highly viscous, black, sticky, and entirely soluble in carbon disulfide and composed primarily of highly condensed polycyclic aromatic hydrocarbons. Known with his naturel origins since the antiquity. In our days comes from the distillation of crude oils. Bitumen plays a large part in determining many aspects of road performance. It is thermoplastic product which has a viscosity that varies with temperature. It is solid at ambient temperatures, but when heated at a temperature higher than 120°C, it can be pumped, carried and used. Therefore, Bitumen is the perfect binder/glue for pieces pavement material, such as pieces of the aggregate [8].

II.2.1. Origin and bitumen fabrication

Bitumen as a hydrocarbon binder is divided to natural and industrial. In nature we find it as the Trinidad or rocks like asphaltic limestone that contain less than 10% in bitumen weight.

Figure. II.1. Pieces of bitumen from the dead sea [9]

Figure. II.2. Naturel bitumen deposit on LAKE ASPHALTE Trinidad[9]

Bitumen is produced by refining crude oil (Figure II.3). The crude oil is pumped from storage tanks, where it is kept at about 60°C, through a heat exchanger system where its temperature is increased [3].

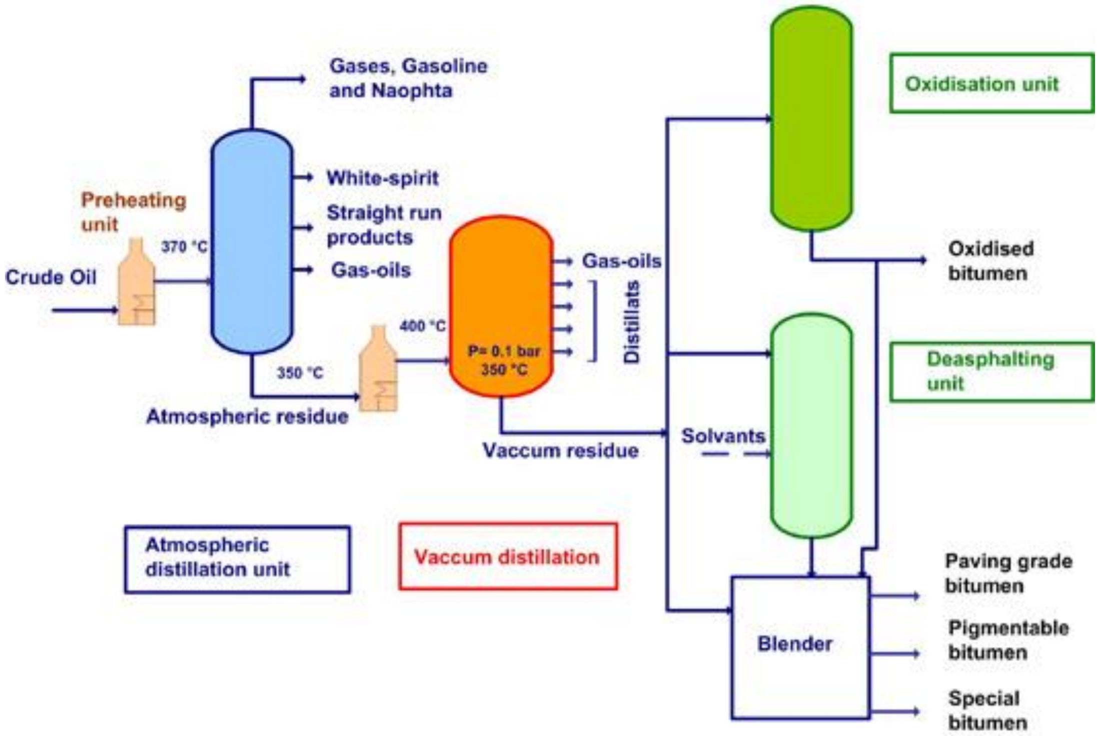


Figure. II.3. Bitumen manufacturing process diagram [9]

The steps of refining crude oil are:

- **Atmospheric distillation:** this process involves crude oil being heated to temperatures of between 300 and 350 degrees Celsius, to separate the different hydrocarbon products (kerosene, gasoline, gas-oil and naphota), known as an **atmospheric residuum**. The lighter fractions re drawn off and sent to other refinery units. To remove the last traces of the lighter fractions and avoid thermal transformation of the molecules, the atmospheric residue is then introduced into a vaccum distillation unit [10].

- **Vaccum distillation**: where the pressure reduction lowers boiling temperatures and avoids unwanted thermal cracking of the molecules. The pressure and temperature conditions within the vaccum process determine the hardness of the residuum, as such, the grade of bitumen produced. After this process the obtained products inter in two different unites, **oxidisation unit** (by blowing air**)** and **deasphalting unit** (adding solvents) [10].

Bitumen can be further processed by blowing air through it at elevated temperatures to alter its physical properties for specific applications. Two types of bitumen can be produced in this way, depending on the degree of oxidation: air rectified bitumen and oxidized bitumen.

Oxidized bitumen is used in roofing applications, while air rectified bitumen is used in paving applications and some roofing applications [10].

Oxidized bitumen has a distinctive consistency at room temperature and a rubbery nature which affects how it responds to stress or imprint. The process of oxidation increases the stiffness and softening point of the bitumen and considerably alters key physical properties.

In the second method, obtained vacuum residue, usually, has very low viscosity and the high degree of penetration of 300-400 mm. The product has low asphaltene, so it is not suitable for making roads in tropical and temperate regions [10].

These two types of bitumen lead us to the next and last step in refining crude oil to produce bitumen by blending.

Blending: Blending the higher and lower viscosity residues in the required proportions can take place at the refinery, at terminals or at a third party facility, where blend components and finished products can be easily transported and distributed for use [10]

II.3. Bituminous products

a) Pure bitumen: Depending on the fabrication mode, bitumen can be obtained with varying consistency, which is determined by the penetrability test according to the results, we can distinguish several classes of pure bitumen[10]:

- Very hard bitumen (20/30)
- Hard bitumen (40/50)
- Semi hard bitumen (80/100)
- Semi soft bitumen ((180/200)
- Soft bitumen (280/300)
- Very soft bitumen (300/350)

b) Cutback bitumen:

These are fluidized bitumen obtained by blending bitumen with a solvent such as kerosene or with lighter oils to reduce their viscosity. This process allows to use them at a temperature lower than that necessary for the implementation of pure bitumen [10].

c) Emulsions :

Stabilized suspensions of bitumen in water, emulsions eliminate the danger of fire and toxic effect that exhibited in the use of cutback [10].

II.4. COLLOIDAL STRUCTURE OF BITUMEN

Bitumen is a hydrogenic compound showing a highly complex composition, bitumen mainly consist in carbon and hydrogen atoms in addition other atoms such as “sulphur, nitrogen, and oxygen” generally present, and traces of metals (Fe, Ca, Ti, Mg, Na, Co, Cu, Sn, Zn) [11].

Table. II.1. Bitumen chemical constituents [11].

Elemental analysis (typical example)	content
Carbon	80/88 wt. %
Hydrogene	8-12 wt. %
Sulphur	0-9 wt. %
Nitrogen	0-2 wt. %
Oxygen	0-2 wt. %
Vanadium,Nickel,Iron, Aluminium,silicon	Traces
Bitumen	600-1500 g/mol

This hydrocarbon mix of bitumen has a molar masses and varied chemical structures. The size of this molecules varied from small to large size (nanometre to tenths of micrometre).However putting bitumen chemistry in global basics it is not sufficient, when try to understand the property of bitumen, the first work on the chemistry of bitumen goes to **Boussingault** who separated in two fraction soluble, he called "petrolenes" now called "maltenes" and insoluble "asphaltenes" .In our days this molecules are generally chemically separated into four chemical families, according the SARA separated fraction. It has be mentioned that the percentage in SARA fraction depends on the crude oil origin, the manufacturing process and the grade of analyse bitumen **[12].**

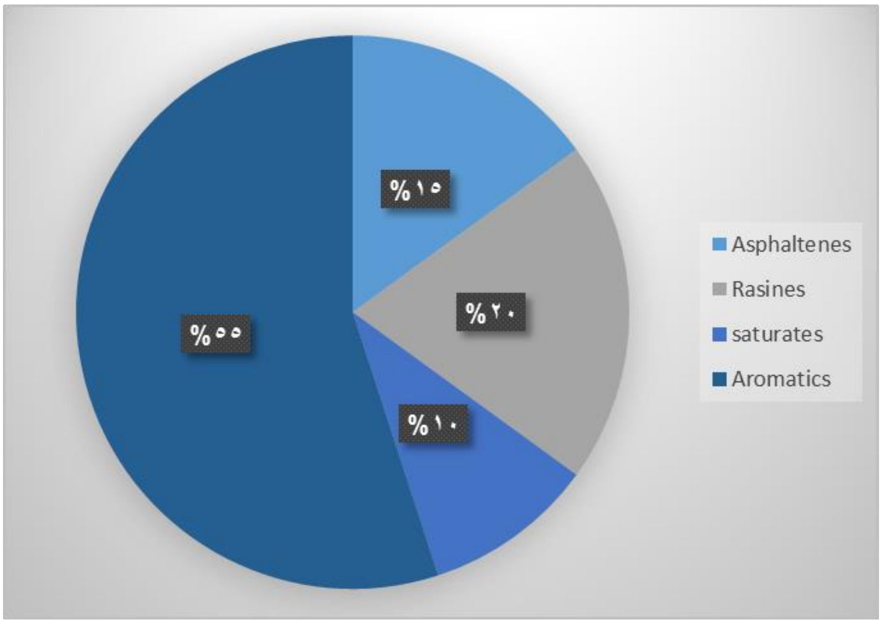


Figure II.4: Typical example of separation into SARA fraction [11]

- **Asphaltenes:** it represents about(10% to 30%)of bitumen and their molar masses is from (1000- 100000 g/mol), it varied depending on origin of bitumen whether was blown or not ,asphaltenes has a hard crumbly black ,brown solid which contributes in the black color of bitumen ,because it heavy compounds **(**carbon

,hydrogen, sulphur, nitrogen, and oxygen) bitumen gets the rheological behaviour with the resistance and stiffness [9].

- **Resins:** ensure the colloidal stability of bitumen, and their surfactant role which make the stability of asphaltenes dispersion in the maleness matrix [9].
- **Oils:** this fraction is the soluble represent to 40% to 60% of bitumen. On general its molar masses is weak and their viscosity can goes high according to chromatography, we can separate oils in to two families (saturates and aromatics) **:**
  - **Saturates:** this fraction can reach only 5 % in bitumen masses and sometimes goes up to 10 % which made it a low molar masses 600g/mol(2).
  - **Aromatics:** the major fraction with 60 %, it has rad, brown and dark colors; it is involved in the glass transition of bitumen. Aromatics have average molar masses about 800g/mol, which gives the viscosity behaviour [11].

The three fractions, Resins, Saturate and Aromatics called maltene.

According to the chemical composition and the respective concentration of constituents of bitumen, colloidal structure of bitumen will be more or less shifted and therefore gives the bitumen different rheological behaviour depending on the temperature.

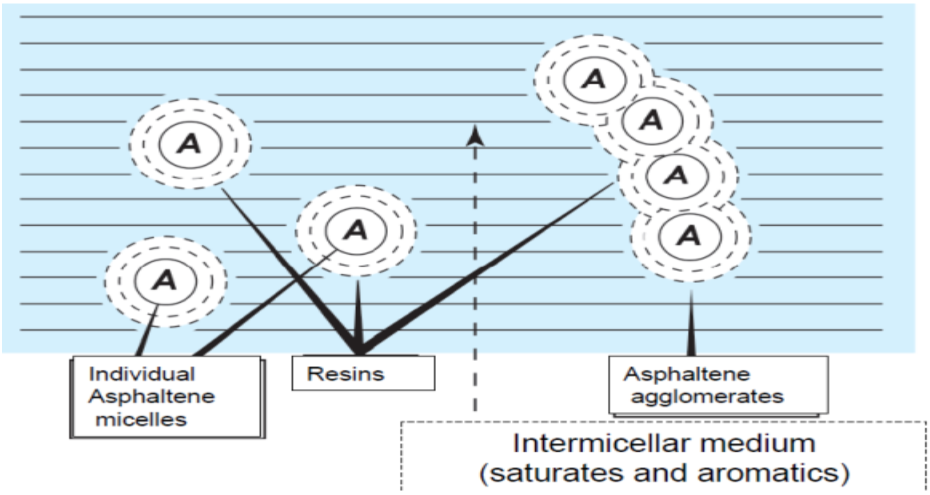


Figure .II.5. schematic model of bitumen colloidal structure [13]

There are three basic types of structures that KOLBANOSKAJA has only classified in function of relative period of varied constituents (Asphaltenes, resins, oils).While DRON, BESTOUGEF and VOINOVITCH accounted the transition temperature between varied states [12].

- **"SOL" structure:** this colloidal structure characterized by the total peptization of asphaltenes molecules resins; this gives it a dilute and well stabilized solution in a dispersing structured by resine. This bitumen with meltenes phase is rich in aromatics and has a viscous behaviour (newtonien).

- **"GEL" structure:** this structure characterized by the agglomeration of asphaltens molecules, with a dispersant environment lacking of resins .Bitumen with gel structure has a wealthy of asphaltens, and in the maltens phase lacking in hydrocarbonic aromatics, that's lead to elastic behaviour.

- **SOL-GEL structure:** this structure is intermediate between the two previous structure .On general pavement are with this structure because of her two important rheological and viscoelastic behaviours.

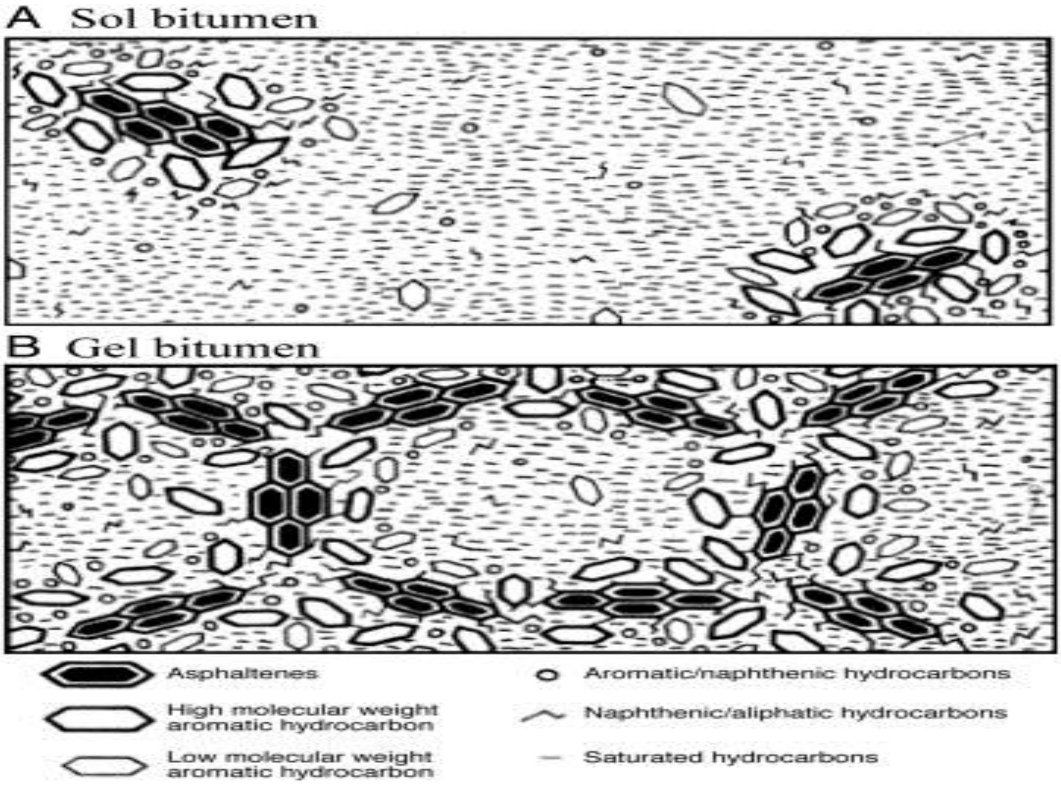


Figure II .6: Model of bitumen structure "Sol" and "Gel"[11]

II.5. THE PURE BITUMEN BEHAVIOUR

The figure II.7, it's identified the main types of bitumen behaviour in function of the deformation amplitude |ε| and temperature T. To get a fixed speed deformation we distinguished:

- The friable and ductile fields where the tensile resist **σp** can be measured;
- The friable fracture, which can be characterized by toughness **Kc** or fracture energy **Gc** (linear fracture mechanics);
- The linear elastic behaviour, characterized by the **E** and **G** moduli;
- The linear viscoelastic field, characterized by the **E*** and **G*** moduli complex;
- The weak viscous behaviour (Newtonien), characterized by the viscosity η ;
- In order of a few per cent deformation, the field where the strong behaviour in inlinear.

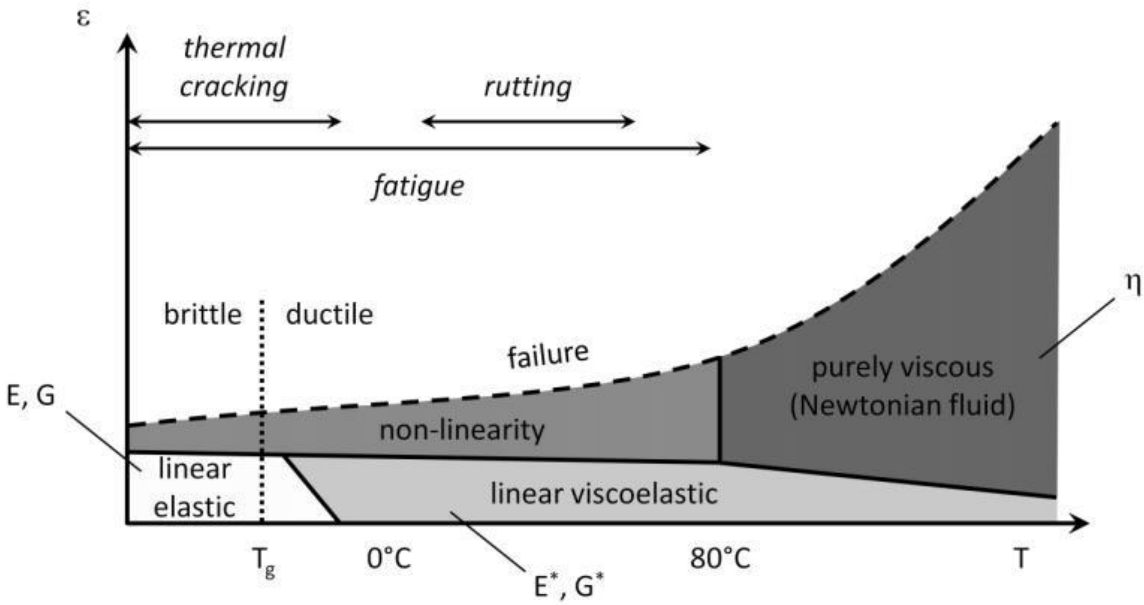


Figure II.7: classes of bitumen behaviour as a function of |ε| and T [9].

II.6. CONCLUSION:

As a conclusion from all of the previous. Bitumen exist in many different types according to his origin and manufacturing process. We can say that bitumen is a highly hydrocarbonic complex mixt with a viscoelastic behaviour.

III.MODIFICATION OF BITUMEN

III.MODIFICATION OF BITUMEN

III.1. INTRODUCTION

Bitumen since it's one of the components of asphalt, he has an important impact on the road performance. For many years, conventional bituminous materials performed satisfactorily. Today we are expecting more from asphalt pavement, and demands made upon roads increase year by year. Traffic grows every day and better performance is needed, including higher standards of safety and comfort [14]. And the climatic change in which we live today its effects, with the increase of temperature year by year.

This what lead for the wide range of modified bitumen, which enable to get the improvement in bitumen resistance against temperature increase, which enable the engineer to meet this challenge.

III.2. OBJECTIVE OF BITUMEN MODIFICATION

An ideal binder should have enhanced cohesion and very low temperature susceptibility throughout the range of temperatures to which it will be subject in service, but low viscosity at the usual temperatures at which it is placed. Its susceptibility to loading time should be low, whereas its permanent deformation resistance, breaking strength, and fatigue characteristics should be high. At the same time, it should have at least the same adhesion qualities (active and passive) as traditional binders. Lastly, its aging characteristics should be good, both for laying and in service [15].

III.3. POLYMERS MATERIALS

The use of plastic material goes back to the antiquity, when it was extracted from animals' horns, turtle scales, lambre and rubber…etc, to get its properties to fabricate a several items by heating up and shaping. In the end of XIXe century new plastic material was discovered with natural polymer chemically modified by chemicals called "semi synthetic plastic ". Most of plastics materials comes from petroleum and natural gaz. They become pillar of humane life, more than 250millions tonnes of plastic are produced each year, mostly from petroleum as it showing in figure III .1 [9].

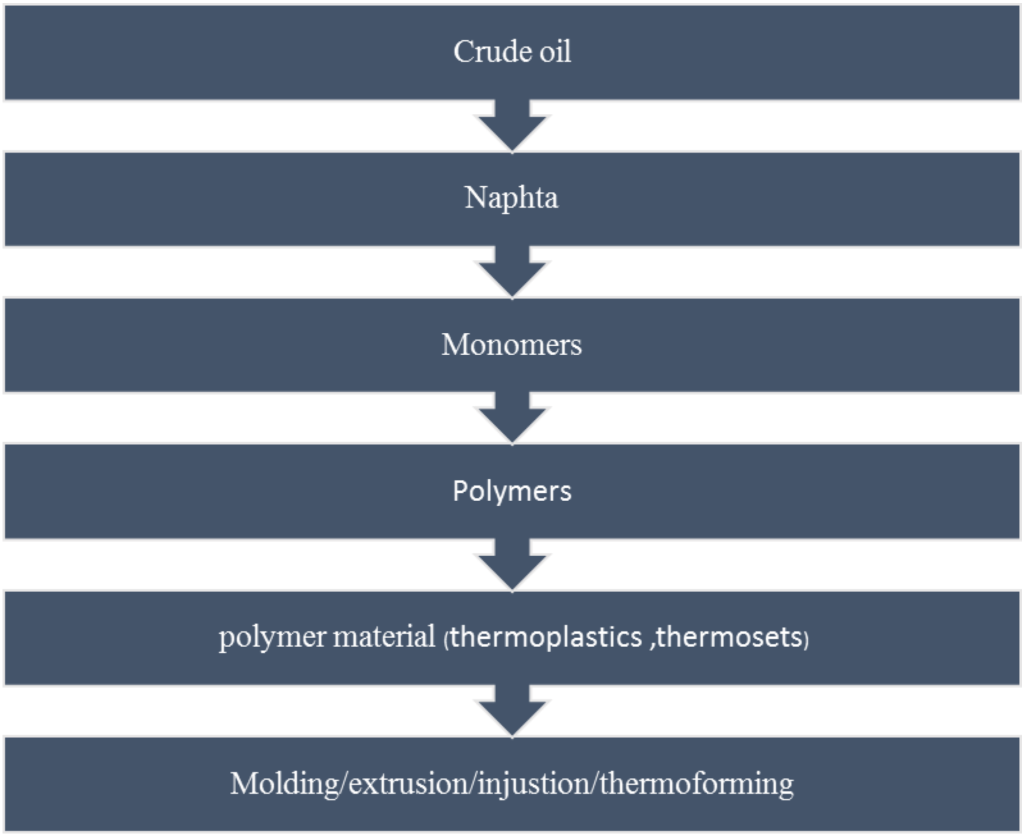


Figure. III.1. Transition crude oil to polymers and plastics.

III.3.1. TYPES OF POLYMERS

For many years modified bitumen have been developed especially for industrial uses, adding fillers, fibers, rubber and polymers. To have a bitumen that is efficient in all conditions of traffic and climate, as well as the gain that can bring to the economy and environment, by recycling used plastic materials. The polymers have proved their effectiveness in the modification of bitumen, because of their existence in the most waste [9].Polymer-modified bitumen (PMBs) became one of the most widely using products.

a) Polymer definition

The word polymer has a GREEK origin which “polus” means several and “moros” means several units or parts.

Polymer are organic substance liquid or solid at room temperature with high molar masses, it is characterized by the repetition of many types of monomeric unites linked to each other by covalent bonds.

The average number of monomeric in a polymer is the degree of polymerization. If it is high degree means a high polymer, while the lowest degree than we called the compound an oligomer.

Industrial polymer can be made from just one type of monomer and called homopolymer, or from several monomer and called copolymer [9].

b) Polymer origin

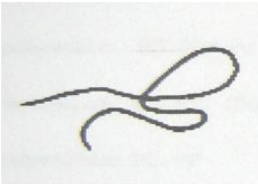
- Natural polymer: they exist in nature according to their plant origin, they are divided to animal or mineral such as rubber, collagen, damylose and cellulose.
- Synthetic polymer: they are often close to natural polymer, although their basic constituents do not exist in nature, such as synthetic rubber and polypropylene.
- Regenerated artificial polymer: they came from the chemical transformation of basic constituents from naturel origin, such as cellulose derivative, their basic molecule is cellulose.

III.4. POLYMER ARCHITECTURE

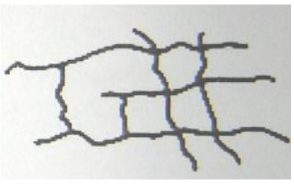
a) Linear polymer: long single chain (high density), figure III.2.(a).

b) Branched chain polymer: one main backbone with short attached, (low density), figure. III.2. (b).

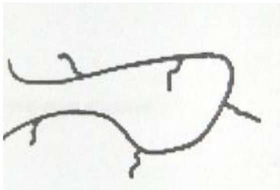
c) Network: covalent bonds between chain crosslink. Low crosslink density like rubber, and high crosslink density like thermosetepoxy. Figure. III.2.(c).



Linear polymer (a)



Branched chain polymer (b)



Network polymer (c)

Figure III.2. Type of polymer [9].

Beside this classification of polymer, there is another one based on their thermals properties, as the following [9]:

a) Thermoplastics: they contain macromolecule linear structure, linked by weak bonds that can be broken either by raising temperature or by dissolution in a suitable solvent. After cooling or evaporation of the solvent, the bonds are re-established and polymer regains its initial state solid, therefore thermoplastics are easy to process and recycle, plus can goes with bitumen at high temperature.

b) Thermosets: they contain of macromolecule forming a three dimensional network .The high temperature or solvent addition does not break the covalent, which gives thermosets the advantage of infusible and insoluble that's means they are not recyclable.

c) Elastomers: they are obtained from linear polymer by crosslinking or valcunization their density is much lower than in thermosets polymer, which leads to the three dimensional structure format vulcanization (bridging) make the transformation of polymer with plastic behaviour into elastic behaviour possible, cause of the slight vulcanization has a large reversible. Elastic deformation can reach 100 **%.** They are difficult to recycle, cause of their resist against the influence of products such as oil**,** essences and they have insensitive to water**,** also they are resistant to oxygen and solar radiation, therefore to natural aging. Elastomer contain from 50 % to 60% of polymer, the rest is fillers, vulcanization, accelerators, delaying aging products and other additives. Elastomer classified into three main families:

- **Elastomers for General use:** like natural rubber (NR);
- **Elastomers for Special use:** like polychloroprene (CR);
- **Thermoplastic elastomer (TPE):** they are not vulcanized with a similar property to rubber vulcaniz.

III4.1. APPLICATION OF POLYMER

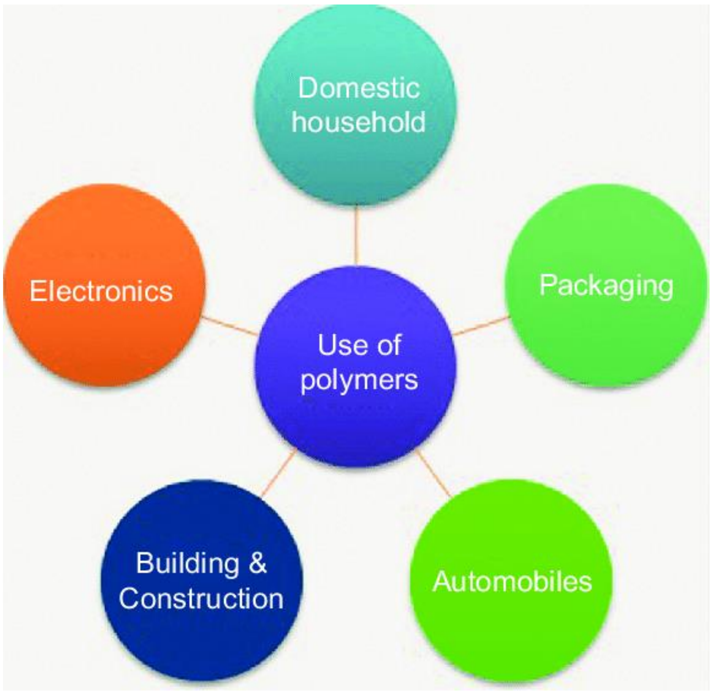


Figure. III.3. Filed of using polymer [16].

After this small view into polymer identification, we can distinguish the polymer type that can be adding to bitumen, such as thermoplastic, thermosets and elastomer, this last is the most using in the bitumen modification, like styrene butadiene and polyethylene.

III.5. MODIFICATION PROCESS

Above all, it should be remembered that there is a complex relationship between the chemical composition of road bitumen, their colloidal structure, and their physical and rheological properties. Anything that modifies the chemical composition of a bitumen unfailingly modifies its structure and, consequently, its properties[15]. However, the performance of pure bitumen now is not sufficient to road industry, this is why we uses and develops modified binders, after about thirty years of bitumen modify and improving it by new additives efficient, less expensive and easy to incorporate into bituminous matrix [12].

Polymer should improve the resistance of bitumen to high temperature without making it too viscous at mixing temperature or too stiff at low temperature.

The major problems posed by modified bitumen reside in the weak solubility of some polymers in bituminous matrix, which can lead to separation .The main group of polymer using in the modification are:

- Thermoplastic polymer
- Natural and synthetic rubber
- Thermoplastic rubber
- Thermoset polymer

Currently, bitumen is modified with thermoplastic rubber in first place, then thermoplastic polymer, natural and synthetic rubbers are hard to applicate as additives.

Polymer proportion in bitumen varied from 2 to 10 **%** by masse in general, but the most used about 5 %, this limit is conditioned by viscosity at operation temperateur.The recycled polymer reduce the total cost of manufacturing modified bitumen .

In our case, we used thermoplastic rubber comes from elastomer families, they are blocks of copolymer of mono and diolefins, as a mono-olefin, styrene is the most used while butadiene and isoprene as diolofins, these copolymer blocks are in SBS or SIS form. Where the “S” referenced to polystyrene, the “B” referenced to polybutadiene and “I” referenced to polyisoprene. These copolymers are distinguished by their styrene content molecular masse and configuration.

Figure III.4. Molecular configuration of SBS [9].

Thermoplastic rubber makes a new class of elastomer that had been stealing industry attention in the past fifteen years, because it combined between processing characteristics of thermoplastic (elasticity properties and resilience). Their three-dimensional network allows them in high temperature to become fluid and wettable, unlike chemically cross-linked rubber, all thermoplastic rubber introduce strong elastic deformation element into bitumen and easily obtain stable dispersions.

Modification by SBS decrease susceptibility thermal increases cohesion and improve the rheological behaviour of bitumen, several SBS copolymers are used as additives in different countries, under different commercial names [9].

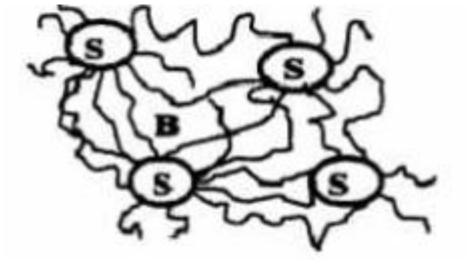


Figure. III.5: thermoplastic rubber structure (SBS):
S: polystyrene, B: polybutadine [9]

III.5.1. Fabrication process of polymer modified bitumen PMB:

Different procedures have been developed to produce bitumen-polymer the main influencing factors, the rate of dispersion of polymer in bituminous matrix are the polymer particle size, temperature and shear applied to the blends. The mixing temperature between 150ºC to 200ºC or more .The mixing period varied from few minutes to few hours , the optimum mixing time is reached when the desired properties of bitumen –polymer are obtaind,such as softening point penetration and the viscosity becomes constant . PMB properties are depending on the dispersion degree of polymer in a bituminous phase, the most important in PMBs performance is the observation of its structure bi microscopy.

The visualization technique is based on the use of fluorescence by simulated UV light the bituminous phase shows no obvious fluorescence .However, some dispersed polymers such as polystyrene produced a greenish yellow fluorescence, a big change in shapes is observed according to the types of polymer used.

The examination of products showed that several of them in form of dispersion, fine or dust, of polymer globules in the continuous phase of bitumen. (figure III.6.a), with increasing polymer concentration and mixing time, a phase inversion can occur causing a real change in the structure of the PMBs and a significant change in its properties (figure III.6.b) [9].

a) Bitumen matrix **b)** polymer matrix **c)** mix matrix

Figure III.6. Microstructure of modified bitumen in three cases [9].

With this physical change that include the mixture of bitumen-polymer, there are some major problems during the preparation and the use of PMBs are:

- The polymer dispersion in bitumen.
- The stabilization of obtained mixtures.

III.5.2 THE MIXTURE (BITUMEN-POLYMER) COMPATIBILITY

The compatibility of bitumen-polymer mixture depends on the composition of crud oil and the manufacturing process of bitumen [9].

The constituent concentration in bitumen plays an important role (solubilizing or swelling agents), in the compatibility of the mixture [9].

The bitumen which is suitable for blending with SBS, should have a high aromatics content and low asphaltene concentration [9]. The tests on mixtures obtained have shown incompatibility of polymer is asphaltene and good dispersion in aromatics and resins. Indeed, the addition of aromatic oil in bitumen –SBS mixtures shows that the concentration must be sufficient for the peptization of asphaltenes and rubbers .All this in purpose for improving bitumen compatibility with polymer.

In basic, all the modification reached the chemical composition of the bituminous matrix by physical or chemical way which leads to the modification in its structure. Although the complex relationship between the chemical composition of bitumen and its colloide structure, its physical propriety and rheological behaviour [9].

The hot mixing of bitumen and polymer gives:

- A heterogeneous mixture: the polymer and bitumen are incompatible means the separate and performance phases of bitumen are not achieved.

- A homogeneous mixture: perfectly compatible ,which the polymer completely covered by bitumen oil and destroy ,all intermolecular interaction, the binder is extremely stable where the properties of use is very low compared to the one in initial bitumen .Only the viscosity is increase, so it is not the desired mixture results.(uncommon case).

- A micro-homogeneous mixture: this is the case with the desired compatibility, which makes it possible to give the bitumen real modified properties, the compatible polymer swells by adsorbing part of the oily fraction of bitumen to form the polymer phase which goes with bitumen form residualing the heavy fraction of the binder (resins, asphaltene and the rest of oil).

III.5.3. MECHANISM OF THE MODIFICATION

For a polymer to be usable for modifying bitumen, it must be at least swellable, possibly soluble in hydrocarbon fraction of low molecular masses binder.

Some researchers believe that, when the polymer is added to the previously heated bitumen, the later immediately begins to penetrate the polymer particles, under the influence of the agitation shear the swollen polymer becomes mobile and disperses in the bitumen.

The dispersion rate depends on the following parameters:

- Temperature: the speed diffusion of bitumen in polymer particulars increase with temperature and the moment changing when shearing becomes effective.
- The particulars size: the smaller they are, the larger is the exchange surface where, and the speed diffusion of bitumen in particulates is high.
- Shearing: the molecules become more movable than, they have been broken, despite the swelling.

III.6. Polymer modified bitumen characteristics

Like the different names that indicate bitumen, the procedure of controlling the composition of bitumen binders is very strict and each country had its way to do the control. The American use a developed technology in the SHRP project, that contains a wide category of binders designed in a propose to require the local weather conditions, all this goes under the superpave system. The opposite direction of the west and east translated in their philosophy in everything, so the Europeans control procedure specially based in different specification according to each country (France, Germany, United kingdom since 1999).Over all they agree to adopt three mains standards:

- The penetrability index (Switzerland and Spain);
- Viscosity at 60°C (Sweden , Finland and Norway);
- Ball and ring temperatures (Germany and France).

To avoid a delicate bitumen at low temperatures, they adopted FRAAS brittleness temperatures specification.Abously the differences between the American specification and the European one because of:

- The American specification are specially based on the determinate modulus under sinusoidal stress or the creep function, they account the evaluation in site by simulating it by the PAV.
- The Europeans specification mainly based on the softening temperature ,this differences made a one-to-one comparison between the two specification system, it can be summarized as the follows :
- In the European specification can use a simple materiel, inexpensive and inrequiring specialized personnel. However, they have a several disadvantages. Consistencies are only appreciated by penetration and temperatures softening indirectly, the interpretation of results shows the one-to-one relationship between these technological data and the effective rheological properties of materials, it is supposed to gain a general culture allowing them to explain and exploit. In a large part imply the encountered difficulties in establish specification for modified binder in site evolution only indirectly account and some arbitrarily are taken.

Conversely, the American specification have the advantage of measuring directly the effective rheological properties of materials but:

- It is requiring the use of more complex and expensive material and specialized personnel.
- Their relevance has not been established yet, in particular as regards stability on set behaviour, the standard taken in account for the evaluation of fatigue resistance has been widely questioned since the establishment of these specification, this standard linked to the search for minimization the waste energy in asphalt. It is valid in the case of thin layers on rigid support. In addition, the two standards relating to rutting and thermal cracking do not fully gathering the diversity of nature and concentration of polymer bitumen.

III.7. CONCLUSION

This chapter present the role of polymer and their principal in modifying bitumen and the changes that happens as result of this complex mixture PMBs and to ensure it stability, compatibility and avoiding the separation. Polymer solubility in bitumen depends on many specification and the most important are:

- ❖ The concentration of bitumen fraction;
- ❖ Nature ,structure and polymer proportion;
- ❖ The temperature and duration of mixture.

Bitumen modification improve it resistance at a different temperature.

The bitumen (pure, modified) characterization methods ,varied from west to east ,the American specified under the SHRP project ,based on dynamic solicitation system reference to road traffic .Unlike the European specified by the empirical relationship between the binder and coating performance.

IV.MATERIAL CHARACTERISTICS

IV. MATERIAL CHARACTERISTICS

IV.1.INTRODUCTION

This chapter present the characteristics of the different materials used in the composition of the asphalt mix, their physico-mechanical and chemical characteristics, that is why we attend throw several tests to recognized , the aggregate size, material density, the Resistance attrition and fragmentation, and the Sand equivalent, and the characteristic of pure bitumen, Penetration and Softening point .

These are the material for testing:

- Gravel class 0/3
- Gravel class 3/8
- Gravel class 8/15
- Bitumen binder

IV.2. HYDROCARBONIC BINDER TEST

To determinate the pure bitumen and bituminous binder under standards there is two tests.

IV.2.1.Penetration test (NF-EN1426)

The standard penetration of a bitumen is defined as the penetration at 25°C of a needle standardized, loaded with 100 g, and left for 5s. It is evaluated in tenths of a mm, which we can calls points (Figure IV.1).

The measurement is made with a device called a penetrometer (Figure IV.1). The standard penetration is in makes the hardness measurement which is used as a basis for the classification of road bitumen. These bitumen are characterized by two numbers that represent the lower and upper limits of penetrability at 25°C.

The standard penetration of a bitumen characterizes its state of viscosity at a standard temperature (25°C), since temperature has a great influence on the hardness of bitumen, it is very important to specify the temperature at which the test is performed [17].

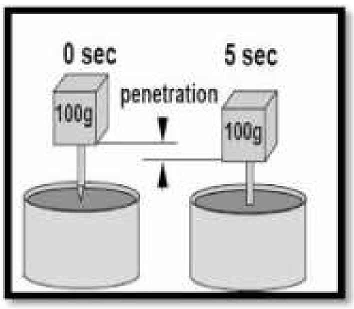


Figure. IV.1. Penetration test

IV.2.2 Softening point test (NF EN 14 27)

The test consists in determining the temperature (noted TBA) for which a standardized steel ball, passes through a bitumen sample held in a metal ring (Figure IV.2), plus the ball - ring temperature is low, the more susceptible the bitumen is to temperature; and the higher it is the harder and less susceptible the bitumen is.

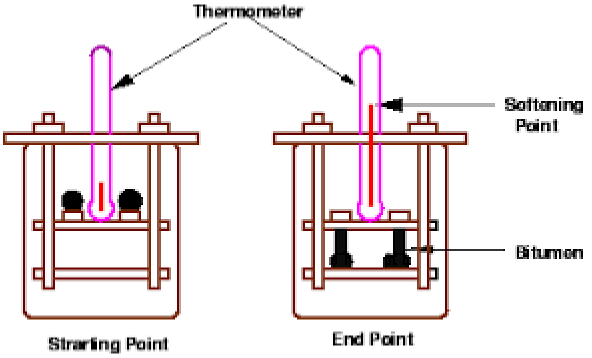


Figure.IV.2. Principle of the softening point test**.**

The results of the two previous empirical tests (penetrability at 25°C and ball-ring temperature) allow to identify the binder under examination and to classify it in relation to the current specifications admitted.

Table IV.1. Hydrocarbon binder tests on bitumen.

Tests	Results		Specification
	Befor e	After	
Penetration at 25 ° (1/10mm)	27.88	12.92	55 **%**
Softening point (Ring and Ball) (° C)	87.90	89.80	$\Delta t = 2°C < 8$
Relative density at 25° C	1.040	1.0466	1 at 1.10

IV.3.GRANULAR

IV.3.1. Gravel:

a) Gradation and size:

After the tested of gravel class (3/8 and 8/15), here it is the granular curves.

- Series 1 (curve of 8/15);
- Series 2 (curve of 3/8);

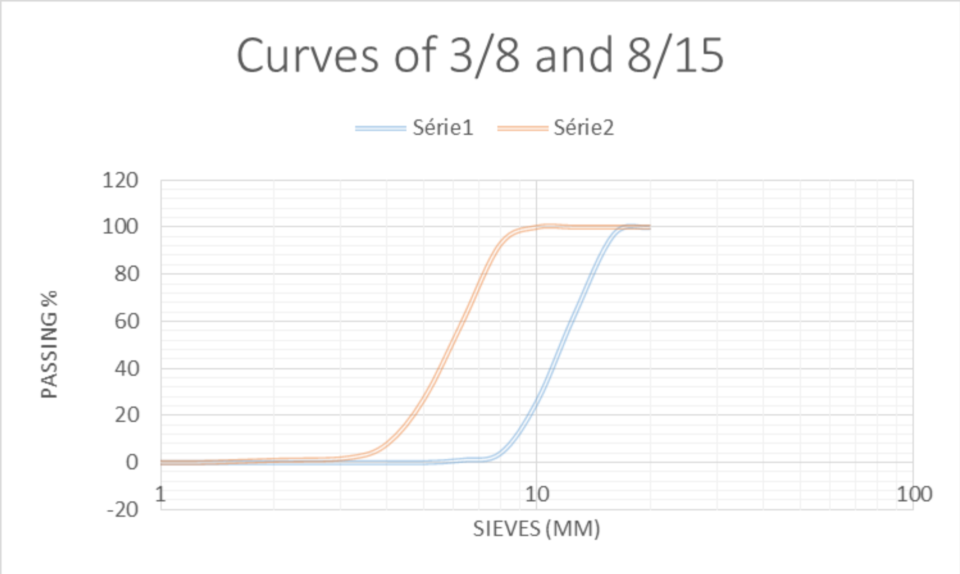


Figure.IV.3. The granulometric curves of 3/8 and 8/15.

b) Absolute density :

The absolute density of aggregate is the ratio of it mass of an equal volume of water.

Table IV.2. Density result.

Gravel class	**3/8**	**8/15**
M.V.R(g/cm³)	0.11	0.11

d) Resistance to attrition using Micro-Deval :

The resistance to attrition of gravels was determinate using the Micro-Deval coefficient (MDE) which is the percentage of the original sample reduced to a size smaller than 1.6 mm during rolling. The sample prepared from the mixed fraction to test portion size in accordance with the requirements of EN 932-2. The test portion shall consist of two test specimens, each having a mass of (500 ± 2) g mixed

with (2.5 ± 0.05) l of water to each drum. For test specimen calculate the micro-Deval coefficient, M_{De}, to the nearest 0.1 units using the following equation:

$MDE = \frac{500 - m}{500}$ with: ***m*** is the mass retained on a 1,6 mm sieve, in grams

Photo.IV.1: Micro -Dival machine and elements

Micro Deval Test results from class 3/8 and 8/15 with the Specifications accordance with the requirements of EN 932-2:

Table .IV.3. Results of Micro-Deval test

Gravel class	3/8	8/15	Specification
MDA **(%)**	28 %	17 %	≤ 25

e) Resistance to fragmentation using Los Angeles:

The resistance of gravel to fragmentation and chocks is evaluated by Los Angeles (L.A) test, where a sample of aggregate is rolled with steel balls in a rotating drum. After 500 tours which a constant speed of 31 to 33 rpm, and when is complete, the quantity of material retained on a 1,6 mm sieve is determined.

The modified laboratory sample prepared from the mixed fractions to test portion size in accordance with EN 932-2. The test portion shall have a mass of (5000 ± 5) g.

Calculate the Los Angeles coefficient LA from the following equation :

$L_A = \frac{5000 - m}{5000}$ With: ***m*** is the mass retained on a 1, 6 mm sieve, in grams

Photos. **IV.2.** Los Angeles test equipment

Test results from class 3/8 and 8/15 with the Specifications accordance with the requirements of EN 932- 2:

Table. IV.4. Results of LA test.

Gravel class	3/8	8/15	Specification
Los Angeles (%)	26 %	24 %	≤ 25

IV.3.2.Sand:

Beside the gravel classes (3/8 and 8/15) we also tested the class (0/3) crushed sand, the below figure shows the granulometric curves of the class.

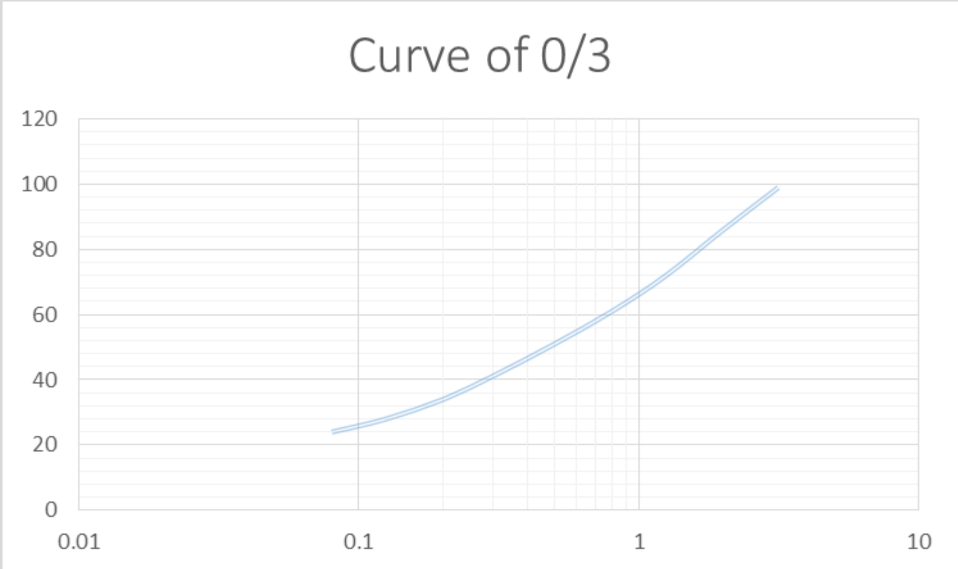


Figure.IV.4. The granulometric curves of 0/3.

a) Sand equivalent test EN 933-8 :

The determination of the sand equivalent value of the 0/3 mm is a determination of cleanness ratio of these sand. A test portion of sand and a small quantity of flocculating solution are poured into a graduated cylinder and are agitated to loosen the clay coatings from the sand particles in the test portion. The sand is then 'irrigated' using additional flocculating solution forcing the fine particles into suspension above the sand. After 20min, the sand equivalent value (SE) is calculated as the height of sediment expressed as a percentage of the total height of flocculated material in the cylinder.

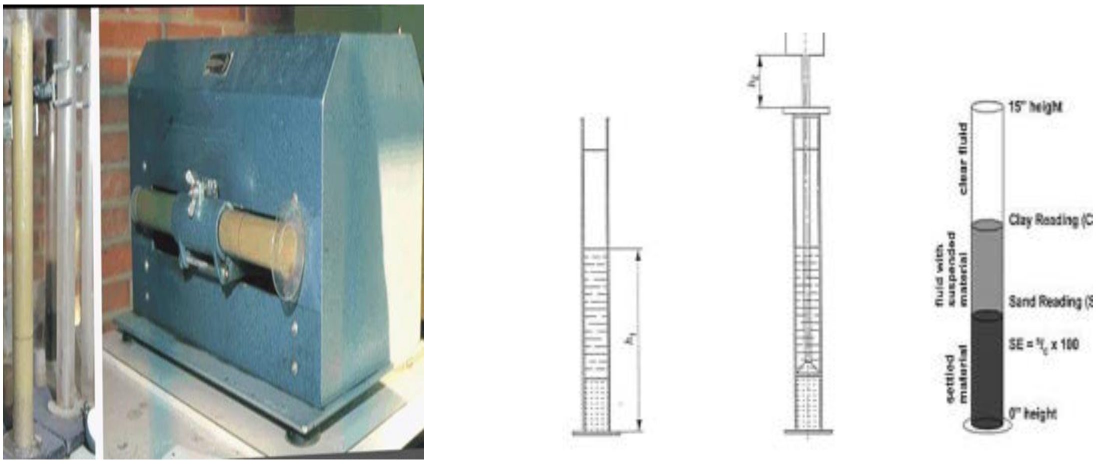


Figure .IV. Sand equivalent test

Calculate the sand equivalent value (SE) as the average of the ratios (h2/h1) x 100 obtained on each cylinder and record to the nearest whole number.

Table IV.5. Sand equivalent value 0/3

Class	SE at 10%	Specification
0/3	70	≥ 45 %

b) Absolute density:

The same as in (3/8 and 8/15), the absolute density of aggregate is the ratio of it mass of an equal volume of water.

Table IV.6. Density results 0/3

Gravel class	**0/3**
M.V.R(g/cm^3)	0.08

IV.4. CONCLUSION

After the modification of bitumen, it presents an increase in performance (hardness) and decrease in thermal sensitivity (TBA), it can be classified as a 10/40 according to

NF EN 14023.

V. THE MIXTURE FORMULA

V. THE MIXTURE FORMULA

V.1.INTRODUCTION

In this chapter, we showed the steps that achieved an asphalt concrete mix, beside the performance tests of this last. And the results of each test in our study.

V.2. FORMULATION STUDY

V.2.1. Granular composition

As we know from the previous work granular are from that main composition of asphalt concrete, where we studied a Hot Mixture Asphalt (HMA) class 0/14, this class composes from three granular class: 0/3, 3/8, 8/15 from Algiers.

Basing on the distribution curves of different granular class (Figure. V.1), a mineral mixture is composed from it.

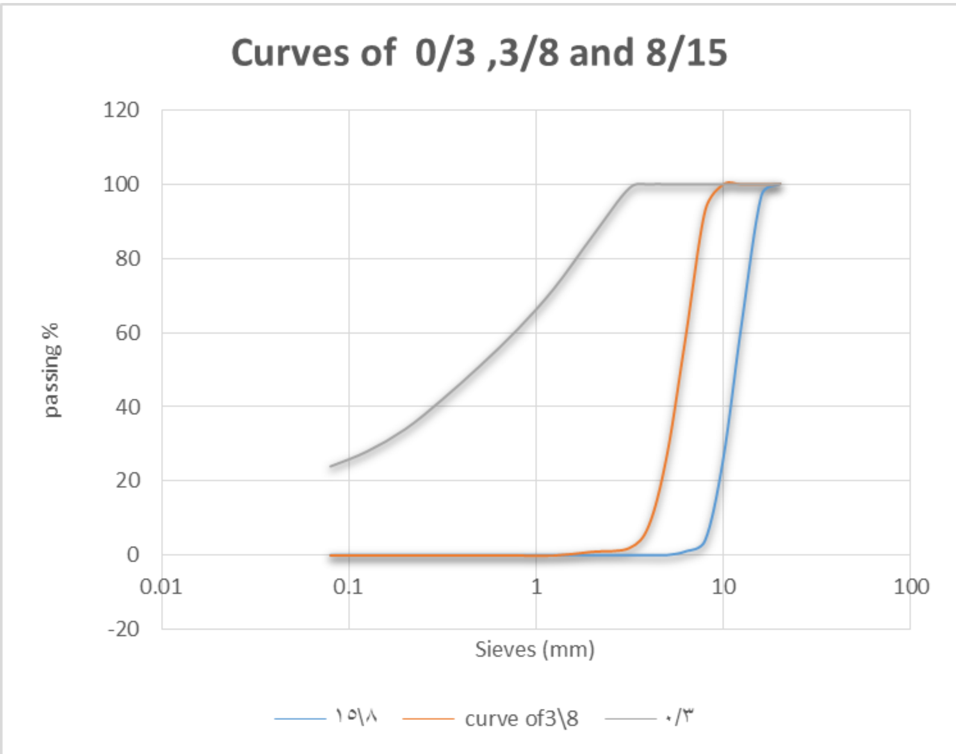


Figure .V.1. The particle distribution curves of the components.

Based on the particle distribution curves of the granular classes, the mineral mixture curve has been calculated (Figure V.2), the percentage of passers-by a sieve for the mixture curve is the sum of the percentages of passers by the same sieve of the component curves weighted by the respective proportions, and the following figure presents the granular composition proposed in this project study:

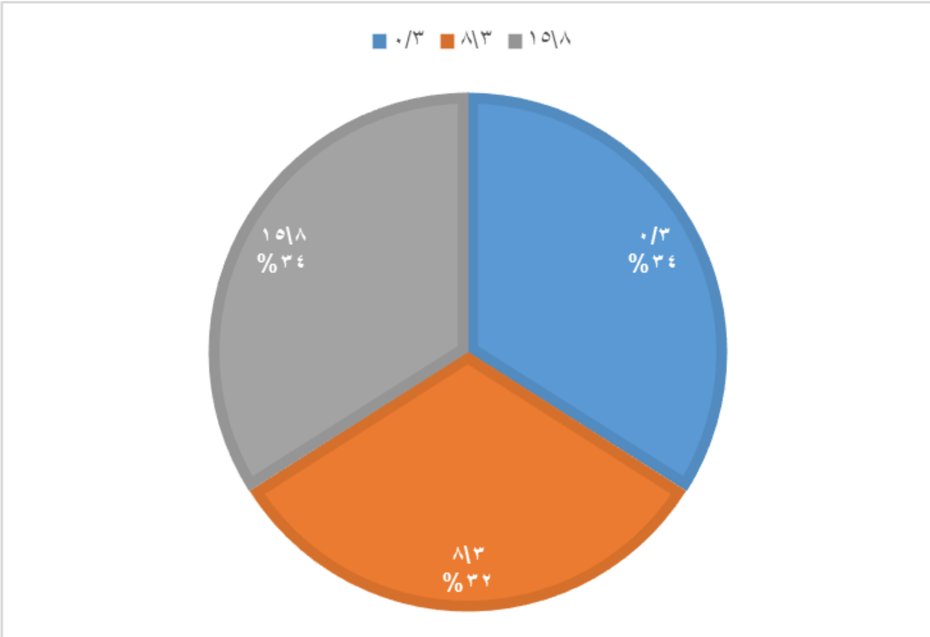


Figure V.2. The mineral composition of bituminous mixture.

The percentages obtained are determined from the grain size curve of each aggregate taking in consideration the reference range 0/14, and the curve is presented in the following figure:

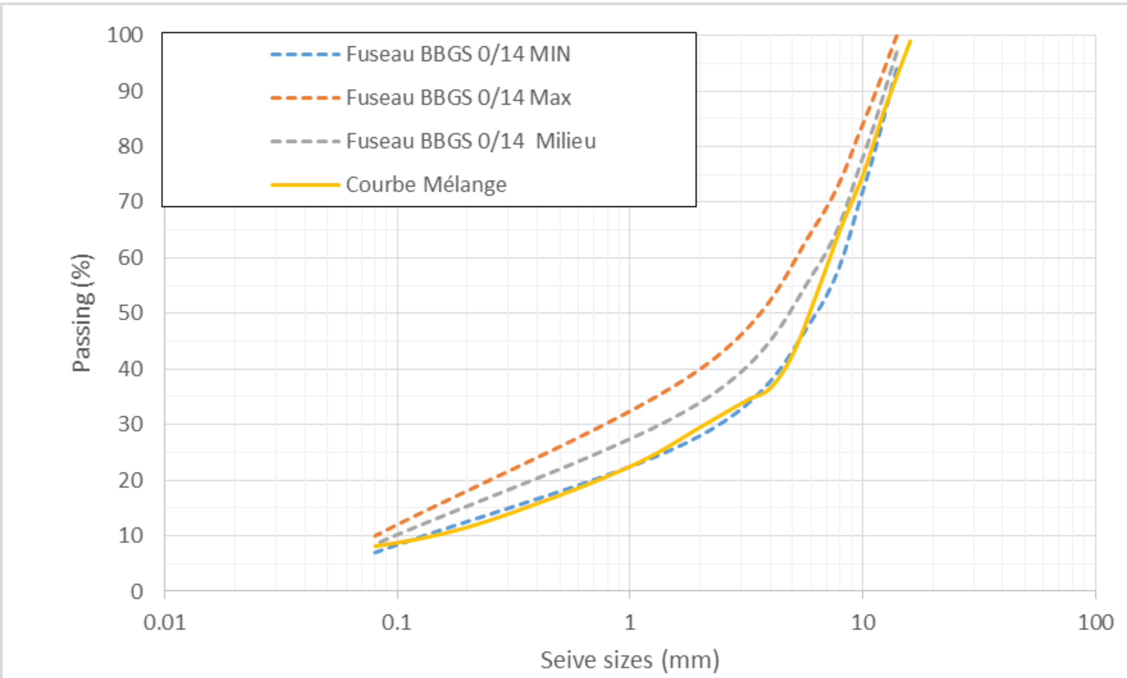


Figure V.3. Mixing curve including the reference range.

V.2.2. Binder content

To calculate the binder content, we should have two basic factors; **the** specific surface area and bulk density corrector factor, these two are determiner following formulas:

a) **Calculation of corrector Coefficient α:**

MVRg = 2.66 g/cc

α =2.65/ MVRg → α = 0.99

b) **Calculation of the specific surface area ∑:**

Σ = (0.25G + 2.3S + 12s + 150f) /100

= 0.25(46.78) + 2.3 (38.94) + 12 (6.12) + 135(8.16)

Σ = 12.762 m^2/kg

c) **Calculation of Binder content:**

In order to calculate the richness modulus "K", we have taken values within the range 3.3 to 3.9 recommaded by Algerian recommendation document and NF EN 13108 – 1 Standard for asphalt concrete 0/14, the (table V.1) presents the richness modulus value and the binder content we obtained for two richness moduli selected:

Table.V.1. The binder content calculates the formulation**.**

Richness modulus (K)	3.4	3.6
Bulk density Corrector factor	0.99	
Specific Surface Area (m^2/kg)	12.76	
Binder Content (%)	**5.6**	**5.8**
Reel density (g/cc)	2.45	2.46

V.3. CONCLUSION

In the end of this chapter we present the different steps and process of determination of percentage of each components of our asphalt mixture, we find a good continues curve of the mixture which respect the granular distribution requirement.

The determination of binder ratio follows the Duriez method, where we change the thickness of binder cover the aggregates using the richness modulus "K", and we sort by two binder ratio 5.6 and 5.8 %.

In the end four asphalts concretes using the two binders mixed, two using pure bitumen which is available in Algeria, 35/50; and two others used modified bitumen by caoutchouc.

The results are shown in the next chapters.

VI.PERFORMANCE RESULTAS

VI.PERFORMANCE RESULTAS

VI.1 INTRODUCTION

The design study generally depends on the type of asphalt mix, the level of stress on the pavement and the size of the construction site. Most asphalt mixes require at least the minimum requirement of formulation which compose of two levels, except for some case such as the high modulus asphalt mixes, which the standard recommends for the maximum requirement where we extent to a four levels study. Each level composes of some characterization test, those tests are:

- ❖ For the level 1: the compactability using the gyratory compactor and water sensitivity,
- ❖ For the level 2: rutting resistance,
- ❖ For the level 3: Modulus,
- ❖ For the level 4: Fatigue resistance.

VI.2.THE GYRATORY SHEARING PRESS TEST [NF EN 12697-31]

The goal from this test, is the study of the compaction behavior of hydrocarbon asphalt mixes using the modified bitumen (PMB) compared to the pure one (BP), the results shown in the table VI.1, and the graphic representation present in the figure VI.1.

Table VI.1: Results of the PCG

Bitumen ratio (%)	5.6% PB	5.6% PMB	5.8 % PB	5.8 % PMB
Void at 10 gyrations (%)	15.47	12.51	13.68	12.64
Void at 80 gyrations (%)	**7.83**	**5.04**	**5.85**	**4.90**
Void at 200 gyrations (%)	4.80	1.82	2.60	1.58

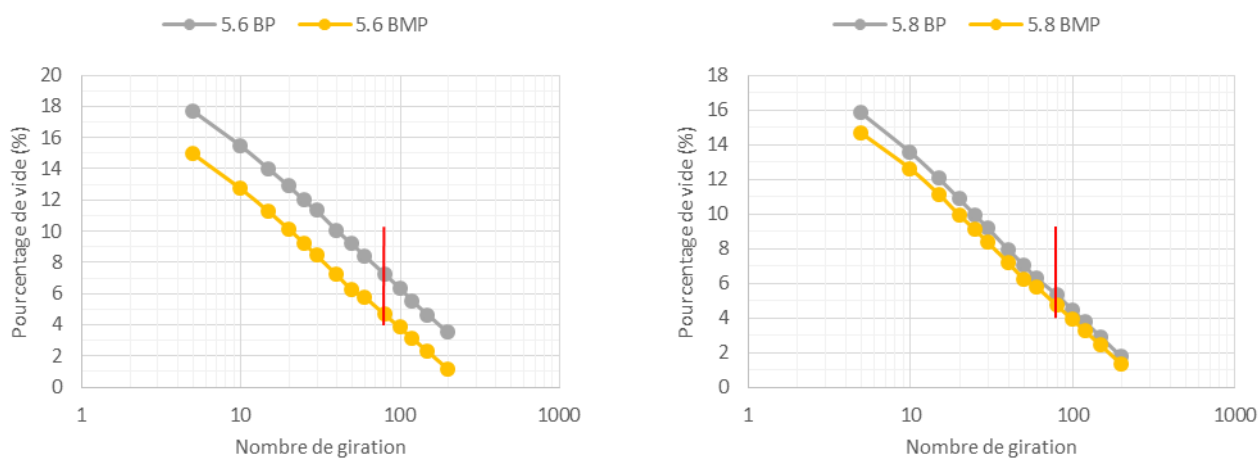


Figure VI.1. Curve evolution of void percentage as a function of the number of gyrations.

According to the specifications of NF EN 13108 - 1: BBSG Class 03 the void at 80 gyrations is between 4% and 9%. We found that the modified asphalt mixes are more compactable and easier to lay and are more resistant to corrosion. Void percentages are reduced by 19 to 55% (increase in compactness …etc.)

VI.3. WATER SENSITIVITY TEST – METHOD (B) [NF EN 12697 – 12]

This test makes it possible to evaluate the water sensitivity of an asphalt mix by measuring the drop in its compressive strength after a 7-day immersion period at 18°C, compared to non-immersion strength at the same temperature and the same period.

The results are shown in the (table VI.2) and (figures VI.2).

Table.VI.2. Results of water sensitivity test.

Bitumen ratio (%)	**5.6 % PB**	**5.6 % PMB**	**5.8 % PB**	**5.8 % PMB**
RC fate wet (*i*) in kPa	8218	9913	10296	10371
RC fat dry (C) in kPa	9736	11715	11686	11923
i/C (%)	**84.41**	**84.68**	**88.11**	**86.98**

All the asphalt mixtures respond to the specifications according to NF EN 13108 – 1 when ***i/C*** $\geq$ **70** %.

The asphalt mixture base on the modified bitumen have compressive strength and a sensitivity to water positive compared to the standard, and it is always resistance to negative impacts of water and has good adhesion between the particle, there is positive impact on the strength and not much in the water sensitivity.

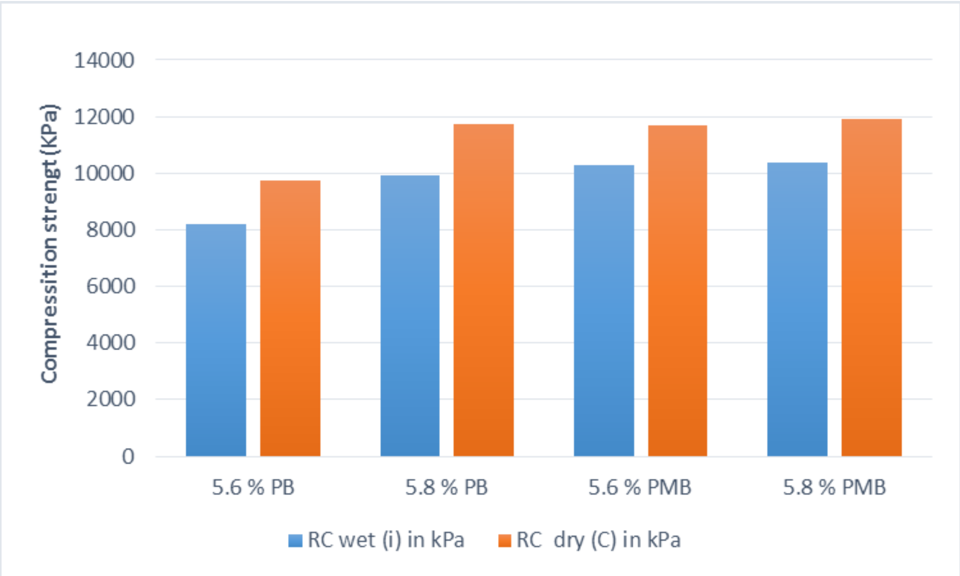


Figure VI.2: histogram shows the comparison between PB and PMB in a wet and dry case

VI.4. RUTTING RESISTANCE [NF-EN 12697-22]

This test is to characterize the resistance to rutting of hydrocarbon asphalt mixes under conditions comparable to road solicitation using simulation machine, the test condition follow the standard NF EN 12697 – 22, which a loading of 5 kN and temperature 60ºC.

The simulation applied a cycling loading from 1 to 30000 cycles, and we measure the depth of the rut as a function of the number of cycles (round – trip) and the thickness of the slab. The results shown in the next table and figure.

Table VI.3: Results of rutting test at 60 °C

	Ratio / Cycles	The rut depth (P) (%)			
		5.6 % BP	5.6 %PMB	5.8 % PB	5.8 % PMB
Rutting test results at 60 ºC	**30**	**0.29**	**0.34**	**1.03**	**0.43**
	100	**0.91**	**0.62**	**1.43**	**0.75**
	300	**1.47**	**0.89**	**1.87**	**1.04**
	1000	**2.15**	**1.15**	**2.36**	**1.35**
	3000	**2.7**	**1.48**	**2.94**	**1.65**
	10000	**3.31**	**1.73**	**3.52**	**1.96**
	30000	**3.91**	**1.98**	**4.13**	**2.25**
	100000	**4.53**	**2.21**	**4.83**	**2.64**

All the mixtures modified and non-modified respond to the specifications of NF EN 13108 – 1, where for the BBSG, the depth of rut (P) at 30000 cycles has to be less then 5 %;

We found that the BBSG based on modified bitumen are more resistant to deformation and rutting at high rutting temperatures, and less sensitive to temperature change compared to BBSG based on pure bitumen, where the deformations measured at 100000 cycles reduced by 83 to 97%.

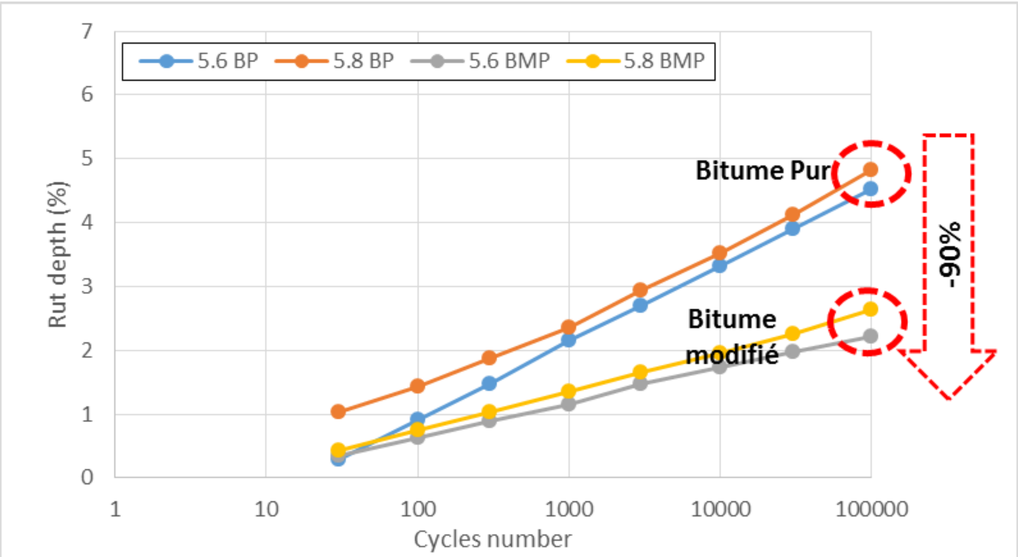


Figure VI.3: Curve shows the evolution between the PB and PMB

VI.5. Stiffness modulus test [NF EN 12697 – 26]

The modulus of rigidity is practically independent of the amplitude of the force in the field linear corresponding to the small deformations. But depends, at a given temperature, on the duration of application of the effort, and conversely, for a given charging time, of the temperature the tested has been realized at 4 specimens and the average values shown in the next table:

Table VI.4: Results stiffness modulus test

Bitumen ratio (%)	**5.6 % PB**	**5.6 % PMB**	**5.8 % PB**	**5.8 % PMB**
Stiffness modulus (MPa)	12421	14226	10250	13367

All the mixture has answered the specification of NF EN 13108 – 1, where the modulus of BBSG has to be higher than 7000 MPa;

The Modified asphalt has a higher stiffness compared to asphalt used the pure bitumen.

VI.6. CONCLUSION:

Based on the different test results, from level 01 to level 03, and at this stage, one can conclude that the modified asphalt mixture can be:

- More compactable and easier to produce the pavement with, which we are not completely sure about, since there is not yet a road fabricates with.
- A High performance and resistant asphalt,
- We can consider as anti-rutting asphalt mixes, which can be a solution effective rutting problem in southern Algeria,
- Asphalt mixes with good stiffness

CONCLUSION

One of the most important material in roads construction is Asphalt concrete. This last has been used for decades. The roads increase year by year, traffic grows every day, and better performance is needed. Today we are expecting more from asphalt pavement.

In this research, we studied an asphalt concrete base on Algerian modified bitumen, its properties and behaviour under simulation condition to the reality or site condition. In the end of this characterisation and literature research, we conclude that:

- ✓ To ensure polymer solubility in bitumen should focus on three mains specification, the concentration of bitumen fraction; polymer properties; the temperature and the duration of mixture.
- ✓ The classics tests on bitumen binder shows a hardness in its performance with a decrease in temperature sensitivity.
- ✓ Any asphalt formulation study must be preceded by the used material characterization (aggregates, bitumen, additives)
- ✓ The formulation study allows to find the best granular formula and binder ratio optimal.
- ✓ The modified and unmodified asphalt concrete characteristics defines at 3 levels.
- ✓ The first level includes (gyratory compactor and water sensitivity tests), shows that the mixture is more compactable and easier to produce pavement with, but until the fabrication is achieved to be completely sure.
- ✓ The modification of a acceptable performance and resistance basing on the water sensitivity test results.
- ✓ For the second level, rutting test results we classified the mixture as anti – rutting asphalt concrete.
- ✓ Asphalt mixes based on modified bitumen has a good stiffness according to the third level test results (stiffness modulus).

The performance of tests in all levels related to the mix class to be formulated that control the passing condition between them. The characteristics of our mix were very good and characterized as BBSG and BBME class 3.

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LIST OF STANDARDS	
NF EN 933	Tests for geometrical properties of aggregates - Part 3: Determination of particle shape - Flakiness index" ; September 2003
NF EN 1097 -1e	"Tests for mechanical and physical properties of aggregates -Part 1: Determination of the resistance to wear (micro-Deval)" ; September 2003
NF EN 1097 -2e	Tests for mechanical and physical properties of aggregates -Part 2: Methods for the determination of resistance to fragmentation" ; July 2006
NF EN 14 26e	"Bitumen and bituminous binders - Determination of needle penetration" ; March 2007.
NF EN 14 27e	Bitumen and bituminous binders - Determination of the softening point - Ring and Ball method" ; 2007
NF EN 12697-31	Bituminous mixtures – Test methods for hot mix asphalt – Part 31: Specimen preparation by gyratory compactor" ; 2005
NF EN 12697 – 26	"bituminous mixtures - Test methods for hot mix asphalt - Part 26: Stiffness "; 2004

Annexe

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

EQUIVALENT DE SABLE A 10 % DE FINES
NF P 18 – 597 Décembre 1990

Structure: U.GHARDAIA
N° dossier interne: 49/
Echantillon: 013
Équipements utilisés: Balance/Etuve

Lieu de travail : SERVICE MATERIAUX
Date: 30/12/2019
Opérateur:
N° D'inventaire: L21-22-15- L49-01-15

1) Détermination de la teneur en eau naturelle

Masse de l'échantillon humide	M h (g)	490,64	
Masse de l'échantillon sec	M s (g)	483,37	
Teneur en eau : $W = \frac{Mh - Ms}{Ms} \times 100$	W (%)	1,50	

2) Détermination de la teneur en fines

Masse de l'échantillon humide (g)	M h = 500
Masse de refus au tamis 0.08 mm (g)	M s = 374,09
Pourcentage de fines : $F = 100 - \frac{Ms\,(100 + W)}{Mh}$	F = 24,06

3) Echantillon pour essai

Si F ≤ 11 % Masse de sable humide : M sh= 120 (1 + W/100) Tamisat à 2 mm (g)	M sh = /
Si F > 11 % Masse de sable humide : M sh = (1200/F)(1+W/100) Tamisat à 2 mm (g)	M sh = 50,63
Masse de sable correcteur : Msc = 120 – (1200/F)	M sc = 70,12

Hauteur totale H 1	Hauteur de sable H 2 (Piston)	ES = (H 2/H 1) x 100	ES moyen %
13,8	43-33,4 = ~~10,4~~ 9,6	69,5	69,1
13,8	43-33,5 = 9,5	68,8	

L'opérateur **Visa du responsable**

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

ANALYSE GRANULOMÉTRIQUE DES GRANULATS
NF P 18- 560 Septembre 1990

Structure: U.GHARDAIA
N° Dossier interne: 29/19
Classe granulaire: 8/15
Prise d'essai: 4000g
Équipements utilisés: BALANCE

Lieu de travail: SERVICE MATERIAUX
Date: 23/12/2019
Opérateur: Bensghier

N° D'inventaire : L21/51/15

Ouverture Tamis	Refus partiel	Refus cumulé	Pourcentage refus	Pourcentage passant	Observations
80					
63					
50					
40					
31.5					
25					
20					
✓ 16	110 g	110	2,75 %	97,25	97
✓ 12.5	1446	1556	38,9	61,6	62
✓ 10	1412	2968	74,2	25,8	26
✓ 8	860	3828	95,7	4,3	4
✓ 6.3	146	3974	99,35	0,65	1
✓ 5	10	3984	99,6	0,4	0
✓ ~~4~~ TN	14	3998	99,95%	0,05	0
3.15					
2.5					
2					
1.60					
1.25					
1					
0.80					
0.63					
0.500					
0.400					
0.315					
0.250					
0.200					
0.160					
0.125					
0.100					
0.080					

L'opérateur

Visa du responsable

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

ANALYSE GRANULOMÉTRIQUE DES GRANULATS

NF P 18- 560 Septembre 1990

Structure: U.GHARDAIA
N° Dossier interne: 49/19
Classe granulaire: 3/8
(1) **Prise d'essai:** 2000 g
Équipements utilisés: BALANCE

Lieu de travail: SERVICE MATERIAUX
Date: 23/12/2019
Opérateur: Bensghier

N° D'inventaire : L21/51/15

100% - RC (%)

RfC x 100 / Prise d'Essai

Ouverture **Tamis**	Refus partiel	Refus cumulé (1)	Pourcentage refus (3)	Pourcentage passant	Observations
80			= (1) x 100 / (2)	100 - (3)	
63					
50					
40					
31.5					
25					
20					
16					
12.5					
✓ 10	0				
✓ 8	140	140	7%	93%	93
✓ 6.3	677	817	40,85	59,15	59
✓ 5	649	1466	73,3	26,7	27
✓ 4	367	1833	91,65	8,35	8
✓ 3.15	123	1.956	97,8	2,2	2
✓ 2.5 ~~EN~~	28	1984	99,2	0,8	1
✓ ~~2~~ T.N	11	1995	99,75%	0,25%	0
1.60					
1.25					
1					
0.80					
0.63					
0.500					
0.400					
0.315					
0.250					
0.200					
0.160					
0.125					
0.100					
0.080					

L'opérateur

Visa du responsable

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

ANALYSE GRANULOMÉTRIQUE DES GRANULATS
NF P 18- 560 Septembre 1990

Structure: U.GHARDAIA
N° Dossier interne: 45/19/
Classe granulaire: 0/3
Prise d'essai: 1250g / 951,68g
Équipements utilisés: BALANCE

Lieu de travail: SERVICE MATERIAUX
Date: 22/12/19
Opérateur: B.N . Ben SGHIR.

N° D'inventaire : L21/51/15

Ouverture **Tamis**	Refus partiel	Refus cumulé	~~Pourcentage~~ refus C	Pourcentage ~~passant~~ R	~~Observations~~ P, D
80					
63					
50					
40					
31.5					
25					
20					
16					
12.5					
10					
8					
6.3					
5 ✓					
4 ✓					
3.15	~~17,50~~	17,50	17.50	1,83 %	98,17 %
2.5	~~161,47~~				
2	~~167,96~~	161,47	178,97	18,70	81,2
1.60	~~140,07~~				
1.25	~~121,50~~	167,96	346,93	36,45	63,55
1	~~117,50~~				
0.80		140,07	487	51,14	48,83
0.63					
0.500		121,50	608,5	63,93	36,07
0.400					
0.315		117,56	726,06	76,29	23,71
0.250					
0.200		103,19	829,25	87,13	12,87
0.160					
0.125		70,05	899,3	94,46	5,54
0.100					
0.080		49,28	948,58	99,67	0,33
0,063	T.N = 5,25g		953,73	100 %	0

Sable grossier (3.15 – 0.315)

Sable Fin (0.315 – 0.080)

L'opérateur **Visa du responsable**

$\frac{1250 - \square}{\square} \times 100 \leq$ 2 % / 1 %.

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

MASSE VOLUMIQUE APPARENTE ET ABSOLUE

MODE OPÉRATOIRE COURS DE LABORATOIRE R.LANCHON

BTS.DUT

49/19

Structure : U.GHARDAIA
N° Dossier interne:
Échantillon: 3/8
Équipements utilisés: balance

Lieu de travail : SERVICE MATERIAUX
Date:
Opérateur: 22/12/2019
N° D'inventaire: L21.51.15

Masse volumique apparente :

Volume du récipient V=5000
Poids P=3800
P_1+T = P_1=
P_2+T= P_2=
P_3+T= P_3=
P_4+T= P_4=
Poids moyen M= $(P_1+P_2+P_3+P_4)/4$ =
Masse volumique apparente P/V =1.53g/cm³

Masse volumique absolue :

Poids des agrégats secs ~~P_1=~~ 300 600 g
Poids du récipient plein d'eau P_2=2094 2172,37
P_3= P_1+P_2=2394 2772,37g
Poids récipient + agrégats + eau= ~~2133,33g~~
P_4=2281 2556,63g
Volume des agrégats V=P_3-P_4= 533g
Masse volumique absolue P1/V =~~2.65g/cm³~~ 0,11 g/cm³

L'opérateur

Visa du responsable

F-5-5i.02

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

MASSE VOLUMIQUE APPARENTE ET ABSOLUE

MODE OPÉRATOIRE COURS DE LABORATOIRE R.LANCHON

BTS.DUT

49/19

Structure : U.GHARDAIA
N° Dossier interne:
Échantillon: ~~3/8~~ 8/15
Équipements utilisés: balance

Lieu de travail : SERVICE MATERIAUX
Date: 22/12/19
Opérateur:
N° D'inventaire: L21.51.15

Masse volumique apparente :

Volume du récipient V=5000
Poids P=3800

P_1+T =	P_1=
P_2+T=	P_2=
P_3+T=	P_3=
P_4+T=	P_4=

Poids moyen M= $(P_1+P_2+P_3+P_4)/4$ =
Masse volumique apparente P/V =1.53g/cm³

Masse volumique absolue :

Poids des agrégats secs ~~P_1=~~ 600g
Poids du récipient plein d'eau P_2= 2182,37 g
P_3= P_1+P_2= 2782,37
Poids récipient + agrégats + eau=
~~P_4=~~ 2555,64g
Volume des agrégats V=P_3-P_4= ~~113~~
Masse volumique absolue P1/V =~~2.65g/cm³~~

L'opérateur

Visa du responsable

Poid P_3 = 600 + 2182,37 = 2782,37 g
V = P_3 + P_4 = 5338,01g
La masse volumique absolue = 0,11 g/cm³

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

MASSE VOLUMIQUE APPARENTE ET ABSOLUE

MODE OPÉRATOIRE COURS DE LABORATOIRE R.LANCHON

BTS.DUT

49/19

Structure : U.GHARDAIA
N° Dossier interne:
Échantillon: ~~3/8~~ 0/3
Équipements utilisés: balance

Lieu de travail : SERVICE MATERIAUX
Date: 22/12/2019
Opérateur:
N° D'inventaire: L21.51.15

Masse volumique apparente :

Volume du récipient V=5000
Poids P=3800
P_1+T = P_1=
P_2+T= P_2=
P_3+T= P_3=
P_4+T= P_4=
Poids moyen M= $(P_1+P_2+P_3+P_4)/4$ =
Masse volumique apparente P/V =1.53g/cm^3

Masse volumique absolue :

Poids des agrégats secs P_1= ~~300~~ 400g
Poids du récipient plein d'eau P_2=~~2094~~ 2182,37
P_3= P_1+P_2= ~~2394~~ 2582,34g
Poids récipient + agrégats + eau= 2433,33 g
P_4=~~2281~~
Volume des agrégats V=P_3+P_4= ~~113~~ ~~600g~~ 149,01
5015,4g
Masse volumique absolue P1/V =~~2.65~~g/cm^3 2,68 g/cm

L'opérateur

Visa du responsable

La masse volumique absolue= 0,079 g/cm^3
0,08 g/cm^3

F-5-5i.02

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

ESSAI DE PROPRETE POUR GRANULAT

NFP 18-591 Septembre 1990

Structure: U.GHARDAIA
N ° Dossier interne: 49/19 -
Échantillon: 3/8 - 8/15
Équipements utilisés: Balance/Etuve

Lieu de travail: SERVICE MATERIAUX.
Date: 30-12-2019.
Opérateur:
N° D'inventaire: L21/51-15-L49/01/15

	Classe 3/8	Classe 8/15	Classe 15/25
Poids humide échantillon P1 (g)	1500,00	1500,00	/
Poids sec échantillon P2 (g)	1479,03	1494,64	/
Formule de la propreté : P(%) = [(P1-P2)/P2]x100	1,42 %	0,35 %	/

L'opérateur

Visa du responsable

F-5-5j.03

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

MICRO DEVAL EN PRÉSENCE D'EAU
NFP-18 572 Décembre 1990

Structure :	Lieu de travail :
N°Dossier interne : 49/19	Date : 31/12/2019
Échantillon :	Opérateur :
Équipements utilisés :	N° D'inventaire :

[2h]

Classe granulaire	Masse abrasive	Poids d'éléments > 1.6 mm m' (g)	Poids d'éléments < 1.6 mm m = M-m' (g)	MDE = 100.$\frac{m}{M}$	Observations
10/14	5 Kg	4	6,3	28%	
		10	14	14%	

L'Opérateur

Visa du responsable

LABORATOIRE DES TRAVAUX PUBLICS DU SUD

LOS ANGELES
NFP-18 573 December 1990

Structure: U.GHARDAIA
N ° Dossier interne: 49119
Échantillon:
Équipements utilisés: Balance/Etuve/LOS .A

Lieu de travail: SERVICE MATERIAUX.
Date:
Opérateur:.
N° D'inventaire: L21/51-15-L49/01/15/L58-06-15.

15min]

Classe granulaire	Nombre de boulets	Poids d'éléments > 1.6 mm m' (g)	Poids d'éléments < 1.6 mm m = M-m' (g)	$LA = \frac{m}{M} \times 100$	Observations
10/14	11				
					%

L'opérateur

Visa du responsable

TL = k.α.(Σ)^0,2

avec : k : Module de richesse : exprime l'epaisseur d'enrobage

α : Coefficient correcteur des masses volumiques

Σ : Surface Spécifique

Surface Spécifique des Agrégats ∑ :

Σ = 0.25G + 2.3S + 12s + 135f

SP=12,76297

Calcul de Coefficient Correcteur α :

α = 2,65 / MVRg

MVRg =2,659

α =0,99

0/3	3//8	8//15
34	32	34
2,68	2,66	2,64
12,69	12,03	12,88
MVRg =	2,6598977	
alfa =	0,99	

K	3.3	3.4	3.5	3.6	3.7	3.8	3.9
TL	5,44	5,60	5,77	5,93	6,10	6,26	6,43

TL adopté			
TL	5,6	5,8	0
K	3,3992468	3,5206485	0
alfaa	0,99	0,99	0,99
SP	12,76	12,76	12,76
Densité théo	2,457	2,462	2,327

Element	Pourc	Densité A	Pourc/De
0//3	34	2,68	12,686567
3//8	32	2,66	12,030075
8//15	34	2,64	12,878788

Granulates composition of the mix class 0/14

Tamis	0/3N	34	3\8	32	8\15	34	Tamis	100
31,5	100	34	100	32	100	34	31,5	100
25	100	34	100	32	100	34	25	100
20	100	34	100	32	100	34	20	100
16	100	34	100	32	97	32,98	16	98,98
12,5	100	34	100	32	62	21,08	12,5	87,08
10	100	34	100	32	26	8,84	10	74,84
8	100	34	93	29,76	4	1,36	8	65,12
6,3	100	34	59	18,88	1	0,34	6,3	53,22
5	100	34	27	8,64	0	0	5	42,64
4	100	34	8	2,56	0	0	4	36,56
3,15	99	33,66	2	0,64	0	0	3,15	34,3
2	86	29,24	1	0,32	0	0	2	29,56
1,25	72	24,48	0	0	0	0	1,25	24,48
0,8	61	20,74	0	0	0	0	0,8	20,74
0,5	51	17,34	0	0	0	0	0,5	17,34
0,315	42	14,28	0	0	0	0	0,315	14,28
0,2	34	11,56	0	0	0	0	0,2	11,56
0,125	28	9,52	0	0	0	0	0,125	9,52
0,08	24	8,16	0	0	0	0	0,08	8,16

Fuseau BBSG 0/14			
Tamis	Min	Milieu	Max
14	94	97	100
10	72	78	84
6,3	50	58	66
2	28	34	40
0,08	7	8,5	10

ملخص :

إن الزيادة في حركة المرور على الطرق والطبيعة الصعبة لمنطقتنا، وخاصة التغير المناخي ودرجات الحرارة المرتفعة، يعتبر الزفت الكلاسيكي المستخدم صعبًا ولكنه قريب من الحد. هذا هو السبب الذي أدى الى إعادة تعريف مواد البناء في الجزائر وكافة الدول الكبرى التي تستخدمه في تصنيع الرصيف والخرسانة الإسفلتية الكلاسيكية إلى وحدات عالية

يتم تحديد هذا النوع من الخرسانة الإسفلتية بمعامل مرتفع للحصول على هذا النوع من المعاملات. وبهذا نصل إلى مادة الزفت الرئيسية لكن الزفت المعدل، وهو خليط بين الزفت والبوليمرات

في هذا البحث تم دراسة هدفنا لقياس الخصائص الميكانيكية المختلفة لخليط الزفت المحقق مع الزفت المعدل مثل سلوك الضغط والمقاومة والصلابة.

الكلمات المفتاحية: الزفت، البوليمرات، الزفت المعدل، الخرسانة الإسفلتية، معامل الصلابة، خليط الاسفلت، المقاومة، سلوك الضغط

Résumé :

L'augmentation du trafic routier et la nature dure de notre région, en particulier le changement climatique et les températures élevées, le bitume classique utilisé est dur mais il est proche de la limite. C'est pourquoi notre pays et le grand pays du monde entier. Ils ont dû redéfinir les matériaux de construction dans la fabrication du revêtement et le béton bitumineux classique en modules élevés.

Ce type de enrobé est défini avec un module élevé, pour obtenir ce type de module. Nous sommes arrivés au bitume principal, mais un bitume modifié, qui est un mélange entre le bitume et le polymère.

Notre objectif est de mesurer les différentes caractéristiques mécaniques du mélange de bitume obtenu avec le bitume modifié, telles que le comportement au compactage, la résistance et, le plus important, le module de rigidité.

Mots clés : bitume, polymère, bitume modifies, béton bitumineux, le module de rigidité, mélange de bitume, résistance, comportement au compactage

Abstract:

The increasing in road traffic and the hard nature of our region, especially climatic change and the high temperatures, the classic bitumen has been used are hard but it is close to limit. That why our country and the big country around the world. They had to redefine the construction materials in the manufacturing of pavement and the classic asphalt concrete to high module ones.

This type of asphalt concrete is defined with high modulus, to get this kind of modulus. We came to the main materiel bitumen but a modified bitumen, which is a mixture between bitumen and polymer.

In this, study our aim to measure the different mechanical characteristics of the achieved bitumen mixture with the modified bitumen, such as compaction behaviour, the resistance and the most important the stiffness module.

Keywords: bitumen, polymer, modified bitumen, Asphalt concrete, stiffness modulus, bitumen mixture, resistance, compaction behaviour**.**