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An Overview of the Use of Mineral Fillers in Asphalt Pavements

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ABSTRACT

Mineral filler in hot mix asphalt is an important component of the mixture as the design and performance of hot mix asphalt (HMA) concrete is greatly influenced by the nature and amount of the mineral filler in the mix, excess quantity of filler tends to increase stability, brittleness, and proclivity to cracking. Deficiency of filler tends to increase void content, lower stability, and soften the mix. The filler content is particularly important as it has a major impact on technical properties and, hence on potential end use. The gradation, shape, and texture of the mineral filler significantly influence the performance of hot mix asphalt in terms of permanent deformation, fatigue cracking, and moisture susceptibility. Better understanding of the effects of fillers on the properties of mastics and HMA mixtures is crucial to good mix design and high performance of HMA mixtures. This paper presents an overview of mineral fillers used in pavement mixtures their benefits and the laboratory tests used to characterize mineral fillers, the effects of mineral fillers on some properties of asphalt mastics and HMA mixtures and introduce some new perspectives on mineral fillers and their role in determining the performance of HMA are presented along with a summary of selected work reported in the literature.

INTRODUCTION

The importance of mineral fillers in the bituminous mixtures have been over looked where their effect was considered to be only filling the voids in the mixture and fulfilling the gradation criteria (Anderson *et al*., 1992). However, recent researches demonstrate that they are more than just filling the voids in the aggregate particles. Mineral fillers serve a dual purpose when added to asphalt mixes. The portion of the mineral filler that is finer than the thickness of the asphalt film and the asphalt cement binder form a mortar or mastic that contributes to improved stiffening of the mix. The particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles. The particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles.

The purpose of this article therefore, is to review various research studies that characterize the mineral fillers, the rheological and the viscoelastic behavior of asphalt binders, mastics (asphalt binder plus mineral filler) and asphalt concrete mixtures. It will contain aspects about how important are the asphalt binders for the mixtures, how mineral fillers affect the overall behavior of mastics and mixture.

Definition of Mineral Filler:

The two constituent parts that make up hot mix asphalt (HMA) are asphalt cement and mineral aggregate. A further breakdown of the mineral aggregate produces three categories: coarse aggregate, fine aggregate and mineral filler. Coarse aggregate is defined as the fraction of aggregate retained on the 4.75 mm sieve (#8 sieve)

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and higher. Fine aggregate is then classified as the material passing the 2.36 mm sieve and retained on 0.075 mm sieve.

The term mineral filler is typically referred to the mineral fine particle with physical size passing the 200-mesh sieve (smaller than 75 micron). Mineral fillers are by-products of various stone crushing procedures, manifesting the feasibility of including them in the design of hot mix asphalt (HMA). Mineral fillers consist of finely divided mineral matter such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, marble dust, dolomite, lime stone, Portland cement, coal dust, sewage sludge dust, waste (tire) rubber and plastic, recycled crushed glass (cullet), roofing shingles, mill tailing, fiber. There is no universal definition, however, for mineral filler. In general terms, fillers are typically fine powders with a particle size distribution in the range of 1-100 micron (μm).

Filler is defined in ASTM D 242, "Standard Specifications for Mineral Filler for Bituminous Paving Mixtures," as consisting of finely divided mineral matters such as rock dust, slag dust, hydrated lime, hydraulic cement, fly ash, loess, or other suitable mineral matter". The specification further requires that 100 percent shall be finer than 600μm, 95-100 percent shall be finer than 300μm, and 70 –100 percent shall be finer than 75μm.

Tunnicliff, (1962) tried to define mineral fillers in terms of what is filled, what does the filling, and why the filling is done. He provided definition to mineral filler as "Filler is that portion of the mineral aggregate generally passing the 200 sieve and occupying void spaces between the coarser aggregate particles in order to reduce the size of these voids and increase the density and stability of the mass." In this definition the filler reduces the voids as well as increases the stability and is composed of material passing the #200 sieve. Tunnicliff concluded that only the part smaller than 75μm or maybe 50μm can be considered as filler. Another definition given is: "Filler is the mineral material that is in colloidal suspension in the asphalt cement and results in cement with a stiffer consistency." The filler in this definition is in the asphalt mastic and stiffens the asphalt as well.

Another definition was proposed by Tunnicliff, (1967) he proposed that filler is the portion of aggregate that passes the #200 sieve, will perform satisfactorily in the presence of moisture, and has, through experience, been deemed to produce successful pavements. Therefore, mineral filler must not contribute to the moisture damage of the asphalt pavement.

Puzinauskas, (1968) provided mineral filler definition as follows: "Mineral fillers play a dual role in paving mixtures. First, they are a part of the mineral aggregate-they fill the interstices and provide contact points between larger aggregate particles and thereby strengthen the mixture. Second, when mixed with the asphalt, mineral fillers form a high-consistency binder or matrix which cements larger aggregate particles together." This definition combines the two points that Tunnicliff expressed separately. It describes the dual nature of the mineral filler in asphalt concrete.

Wypych, (1999) stated that:filler can be defined as "solid material capable of changing the physical and chemical properties of materials by surface interaction or its lack thereof and by its own physical characteristics". This definition implies the existence of two ways in which fillers modify a system. Firstly, the ways in which the filler's shape, particle size and particle size distribution affect the system through filling of the liquid with solid particles. Secondly, the way in which interactions between the solid and liquid phases of the mixture affects the material. The second interactions can vary from strong chemical bonds or physical interactions leading to strongly reinforced materials, to almost no interaction at all.

Types of Mineral Fillers:

The filler raw materials mostly are quarry products and subjected to post conditioning and processing and can be divided into four categories.

The first category is fillers extracted from natural minerals (Andesite, Basalt, Caliche, Dolomite, Granite, and Limestone) by mechanical sieving after quarry operation. These materials are usually referred as Quarry Dust (QD), Washed Mining Sand (WMS), River Sand (RS), and Limestone (calcium carbonate) Powder (LSP). These materials consist of mixed fine aggregate (2.36mm to 75μm) and fine particle (less than 75μm) and are the most common used fillers in HMA.

Second category of fillers is the post-conditioning fillers or manufactured fillers (Hydrated Lime, Fly Ash, and Slag). This category refers to Hydrated Lime Powder (HLP) and Carbon Black (CB). The use of these materials is specifically for anti stripping purpose.

The third category refers to fillers with combination of chemicals and natural minerals which undergoes special processing before it is ready for use such as Ordinary Portland Cement (OPC). It also reported that other fines derived from industrial wastes (power station) such as fly ash.

Other common fillers include silica, kaolin (China Clay), mica, feldspar, diatomite, sulfur, and quartz. The most frequently used filler in asphalt is limestone (calcium carbonate), which is derived from the consolidation of minute micro-organisms during the formation of the earth's crust. Limestone is the general term for rocks where calcite, a form of calcium carbonate, is the predominant mineral. Limestone may also contain a proportion of magnesium carbonate, dolomite, silica, clays, iron oxides and organic material. Other materials commonly used as fillers in asphalt include Portland Cement and Hydrated Lime, which possesses well documented properties with regard to mixture durability and increased resistance to moisture damage in asphalt (Little and Epps, 2001). Additionally, recycled fillers in the form of so-called “baghouse” fines have also been frequently used in asphalt (Kandhal, 1980; Anderson *et al.*, 1982).

Significance and Benefit of Mineral Fillers

Mineral fillers vary in mineralogy, chemical properties, shape characteristics, size and gradation. Mineral filler in hot mix asphalt is an important component of the mixture as the design and performance of hot mix asphalt (HMA) concrete is greatly influenced by the nature and amount of the mineral filler in the mix, excess quantity of filler tends to increase stability, brittleness, and proclivity to cracking. Deficiency of filler tends to increase void content, lower stability, and soften the mix (Anderson et. al, 1996).

Fillers play an important role in stabilizing the HMA by filling the voids within the larger aggregate particles, and improving the consistency of the binder that cements the larger aggregate particles (Puzinauskas, 1969). Mineral fillers increase the stiffness of the asphalt mortar matrix, improving the rutting resistance of pavements, increase density and lower the cost of asphalt mixtures. Mineral fillers also help reduce the amount of asphalt drain down in the mix during construction, which improves durability of the mix by maintaining the amount of asphalt initially used in the mix. Mineral fillers may also be used to fill voids hereby preventing the reduction in the asphalt cement content of a mix, increase the stability and apparent viscosity of the mix, improve the bonding between asphalt cement and aggregate, and also used to meet aggregate gradation specifications.

Too much filler in asphalt mixtures can lead to cracking or fatigue problems as the stiffness is increased. Too little filler can lead to “bleeding” of bitumen from the mixture (Kandhal, 1980; Anderson et al., 1982). Furthermore, they affect the workability, moisture sensitivity, stiffness and ageing characteristics of HMA (Mogawer and Stuart, 1996). A certain amount of filler is necessary in bituminous mixtures to obtain the required density and strength (The filler particles fill a portion of the space between the coarse and fine aggregate, and thus contribute to increase density). The filler also influences the optimum asphalt content in bituminous mixtures by increasing the surface area (or specific surface) of mineral particles. And simultaneously, the surface properties of the filler particles modify significantly the rheological properties of asphalt such as penetration, ductility, and also those of the mixture such as resistance to rutting.

Anderson, (1987) described the importance of mineral fillers in asphalt mixtures. He summarized the impact of mineral filler on the mixture as follows:

- Given mineral filler may extend the asphalt or stiffen the asphalt.
- Mineral fillers benefit the mix by stiffening the mix at high temperatures with less stiffening at lower temperatures, and by toughening the mix at low temperatures.
- The amount of free asphalt can be used to predict the amount of stiffening indicating that this is a free volume phenomenon.

The effect of mineral fillers is more prominent in gap graded asphalt mixtures, such as the stone matrix asphalt (SMA) mixture that contains large amounts of fines. Mineral fillers serve a dual purpose when added to asphalt mixes. The portion of the mineral filler that is finer than the thickness of the asphalt film and the asphalt cement binder form a mortar or mastic that contributes to improved stiffening of the mix. The particles larger than the thickness of the asphalt film behave as mineral aggregate and hence contribute to the contact points between individual aggregate particles. The gradation, shape, and texture of the mineral filler significantly influence the performance of hot mix asphalt.

Ideal asphalt filler used in HMA aimed to the following primary objectives:

- To obtain stiffer mixes at high service temperatures to reduce rutting susceptibility.
- To obtain softer mixes at low service temperatures to minimize thermal cracking.
- To improve the asphalt-aggregate bond to improve resistance to stripping or moisture damage.
- To improve resistance to abrasion this in turns reduces other forms of surface disintegration.
- To rejuvenate aged asphalt binders.

Fillers also contribute to workability, compaction characteristics, voids in the mix, etc. As different filler possess different properties, they can alter the physical or chemical properties of the binder in different ways (Kavussi and Hicks, 1997). This alteration process largely depends on the following factors:

- Type of filler
- Physico-chemical activity of filler, and
- Concentration of filler in the mix.

Characteristics of Mineral Fillers:

The characteristics of mineral fillers such as particle size, gradation, shape of the particles can have a detrimental impact on asphalt mixtures because of their impact on mixture stiffness, air voids content, moisture sensitivity, and thus can have a significant effect on mixture performance (Dongre, 2002). The filler particles finer than 20 micron (μm) are a major factor governing the behavior of fillers as they possess the highest surface area (Anderson *et al.*, 2001). The presence of super fine filler (extremely fine particles) in the mix could be the main possible contributor to premature failure (cracking, stripping and brittleness) of hot mix asphalt. Also, the production of excess fines during the aggregate production process has made it necessary to re-evaluate the effect of such material on hot mix asphalt. Each type of filler has different characteristics that influence the end properties of the finished products in which they are used (Wypych, 1999).

Kavussi and Hicks, (1997) proposed that in order to provide satisfactory properties in the finished asphalt, satisfactory filler should:

- Not have adverse chemical reactions with bitumen.
- Not possess hydrophilic surfaces to ensure good adhesion.
- Not possess high porous particles which may lead to excessive stiffening through selective adsorption.
- Have a high affinity for bitumen.
- Contain a dense (well graded) Particle Size Distribution.

Some of the more important properties of mineral filler used in asphalt concrete applications are as follows:

- Gradation – mineral fillers should have 100% of the particles passing 0.60 mm (No. 30 sieve), 95 to 100% passing 0.30 mm (No.40 sieve), and 70% passing 0.075 mm (No.200 sieve).
- Plasticity - mineral fillers should be non plastic so the particles do not bind together.
- Deleterious Materials - the percentage of deleterious materials such as clay and shale in the mineral filler must be minimized to prevent particle breakdown.

With regard to the specification of fillers, Table 1 provides specified limits of quality requirements for mineral filler for Bituminous Paving Mixtures AASHTO M17.

Table 1: Specification Requirements for Mineral Filler Use in Asphalt Pavement.

Particle Sizing		Organic impurities	Plasticity index
Sieve size	Percent passing		
0.60 mm (No. 30)	100	Mineral filler must be free from any organic impurities	Mineral filler must have plasticity index not greater than 4
0.30 mm (No. 50)	95-100		
0.075 mm (No. 200)	70-100		

Table 2 provides a listing of applicable test methods containing criteria that are used to characterize the suitability of conventional filler materials for use in asphalt paving applications.

Table 2: Mineral Filler Test Procedures.

Property	Test method	Reference
General Specification	Mineral filler for Bituminous Paving Mixtures	ASTM D242
Gradation	Sieve Analysis of Mineral Filler for Road and Paving Materials	ASTM D546
Plasticity	Liquid Limit, Plastic Limit, Plasticity Index of Soils	ASTM D2419
Deleterious Materials	Sand Equivalent Value of Soils and Fine Aggregate (Indirect measure of clay content of aggregate mixes)	ASTM D2419

In early times, several tests have been used to characterize and evaluation of the mineral filler in bituminous mixes was dependent heavily on routine laboratory tests. These tests were mostly from soil mechanics and included liquid limits, plasticity index, cementation, shrinkage, and water-bitumen preferential test (to eliminated hydrophilic fillers). However, the more experience, the following tests (Table 3) are performed nowadays to characterize the mineral filler (materials passing the 0.075 sieve); the index properties of fillers, typically particle size distribution, particle shape, surface activity and the void content of filler in its compacted state, standard sieving, hydrometer tests, special sedimentation tests, Blaine fineness tests, methylene blue tests, and plasticity index, kerosene Absorption test, Rigden Voids BS 812, particle size analysis, and German Filler Test - Koch Materials Company Procedure.

The evaluation techniques for mineral fillers or fines are essential to improve our understanding of the chemical composition and behavior of different fillers and to the development of performance based specifications. Further using of microscopic techniques, such as Energy-dispersive X-ray spectroscopy (EDX) for example, will enable better measurement of fillers/or fines mineral composition. These new non-destructive techniques capable of determining filler structure properties would contribute greatly to understanding the chemical interaction of asphalt and mineral fillers. Aside from their chemical composition, fillers are traditionally characterized by their particle size distribution, shape, particle packing, surface area and surface activity (Wypych, 1999).

Table 3: Some of the key properties of fillers and their means of measurement

Property/ Test protocol	Standard
Geometrical	
I. Particle size distribution: Air-Jet, Sedimentation , and microscopy (Laser diffraction) technique	EN 933-10/ BS ISO13320-1:1999
II. Particle shape and texture: Scanning Electron Microscopy technique (SEM)	-
Physical and Mechanical	
I. Water content	EN 1097
II. Particle density	EN 1097-7
Stiffening	
I. Voids of dry compacted filler/fractional voids : Rigden voids	EN 1097-4: 1999
II. Delta Ring and Ball	EN 13179-1
III. Absorption: Bitumen number	EN 13179-2
IV. Loose bulk density in kerosene	EN 1097-3
Chemical	
I. Water solubility	EN 1744-1:1998
II. Water susceptibility	EN 1744-4:2001
III. Calcium carbonate content: x-ray fluorescence	EN 196-21/EN 495-2
IV. Calcium hydroxide (hydrated lime) content of mixed filler	EN 459-2
V. Organic content :Loss on ignition of coal fly ash	EN 1744-1:1998
VI. Organic content :Loss on ignition of blast-furnace slags	EN 196-2:1994
VII. Mineral composition: Energy-dispersive X-ray spectroscopy (EDX)	-
VIII. Requirement for harmful fines: Methlene blue value	EN 933-9
IX. Plasticity Index	BS1377: 1990 Part 2 1
Surface area - fineness	
I. Blaine test (Blain specific surface)	EN 196-6

Concept of Free Asphalt:

The concept of free volume is critical to the development a proper understanding of the role of mineral filler in the mix and its effect on HMA performance. This concept was first reported by Rigden where the dry-compacted voids of mineral fillers were measured as illustrated in Figure 1. Rigden, (1947) proposed that the volume of fixed asphalt that a filler could accommodate in its compacted state influenced the stiffening behavior of fillers in mastics. Rigden also proposed that the volume of “fixed asphalt” that the system could accommodate scaled the effects of a given volume of filler.

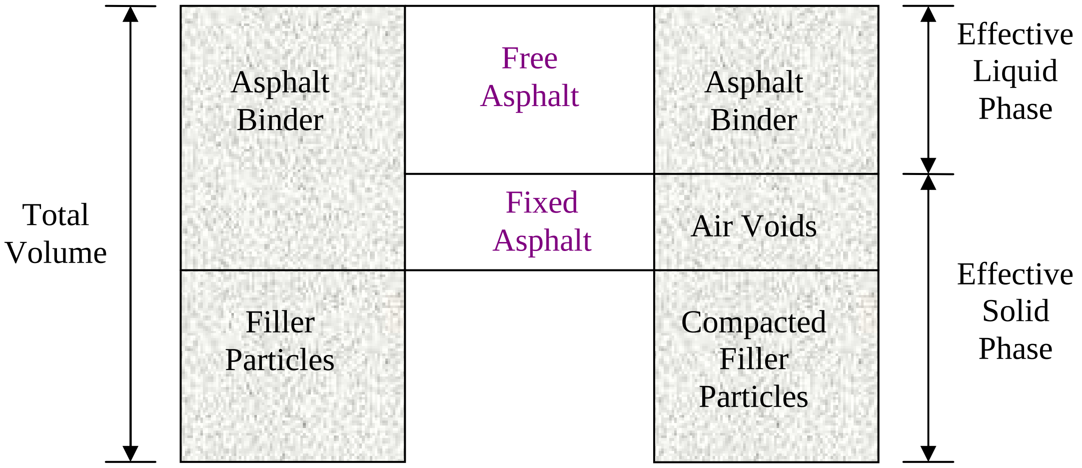

Fig. 1: Concept of Free Asphalt (after Rigden, 1947).

In this concept, the mineral filler particles assume some minimum packing that is unique to that filler. The minimum packing or void content depends on a number of factors, including the gradation of the filler (size and size distribution), the shape of the particles, surface roughness, and the test procedure used to measure void content. The minimum packing can be determined in many different ways, such as dry compaction, kerosene absorption, water absorption. The definition of free asphalt as was first defined by Rigden (1954). When asphalt is added to the mineral filler, the asphalt first fills the voids. Asphalt within these voids is called fixed asphalt (i.e. the amount of asphalt required to fill the voids between the mineral filler particles) because it is fixed within the void structure and does not contribute to the flow properties of the mastic. Asphalt in excess of the fixed asphalt is called free asphalt because it is free to lubricate the larger particles. The free asphalt pushes the particles apart, lubricating the mastic (filler/asphalt mixture) and thereby enhancing its fluidity and contributes to workability. It is the ratio or percentage of the volume of free asphalt (effective asphalt) compared to the total asphalt content that has proven significant in predicting the stiffness of the mastic. It was presumed that high percent voids (low free asphalt content or low effective asphalt) might lead to stiff mixtures of low workability that are susceptible to cracking, and that samples with low percent voids (high free asphalt or effective asphalt) are susceptible to bleeding or shoving. The concept of free asphalt has been defined and found to be an important factor affecting the mineral filler asphalt mastic properties (Rigden 1947; Kandhal 1981).

Mineral Fillers and Asphalt Binders Interaction:

Bitumen acts as a binder in asphalt and binds, or “cements”, the aggregate particles together. There are several types of asphalt binder and the rheological (flow and deformation) properties of the asphalt binder reflect the source of the bitumen (the type of crude from which the bitumen is manufactured), the manufacturing process of the bitumen, and the addition of polymers or additives. Asphalt binders are rheological materials; that is, their behavior depends on temperature and rate (frequency or time) of loading. At any combination of time and temperature, the time-dependent (viscoelastic) behavior of asphalt binder, within the linear range, is best characterized by two properties: the total resistance to deformation under load and the relative distribution of that deformation between elastic and viscous parts (Bahia and Anderson, 1995). Asphalt mastics are defined as dispersions of aggregate fillers within a medium of asphalt binder. When asphalt binders are combined with mineral fillers, a mastic is formed. This mastic can be viewed as the component which glues the aggregate together and which undergoes deformation when the pavement is stressed during the service. The component of filler asphalt mastic is shown in Figure 2.

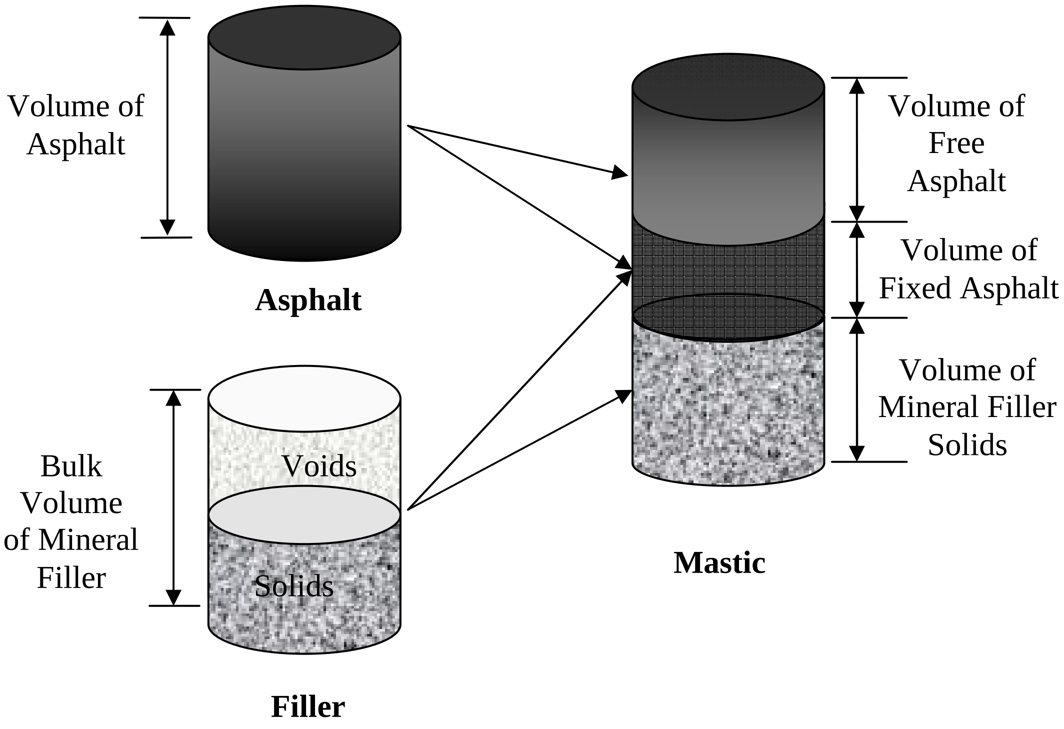

Fig. 2: Components of Asphalt Mastic (Source: Hanson and Cooley, 1997).

The behavior of fillers in different bitumen types is not easy to predict due to the complex nature of the interactions between the two materials. The mastic formed from filler and bitumen in asphalt can be considered the “true binder” of the mixture and thus the properties of the mastic, and hence the properties of filler are important in an asphalt mixture (Anderson et al., 1992a). Buttlar et al., (1999) divided the reinforcement mechanisms into three categories: (a) volume-filling reinforcement (stiffening caused by the presence of rigid inclusions in a less rigid matrix), (b) physico-chemical reinforcement (stiffening caused by interfacial effects between asphalt and filler particles, including absorption, adsorption and selective sorption), and (c) particle-interaction reinforcement (stiffening beyond volume filling and physico-chemical reinforcement caused by interactions between particles of filler/altered asphalt). Figure 3 shows the Basic Concept of Fillers’ Interaction with Binders after Tunnicliff in 1960.

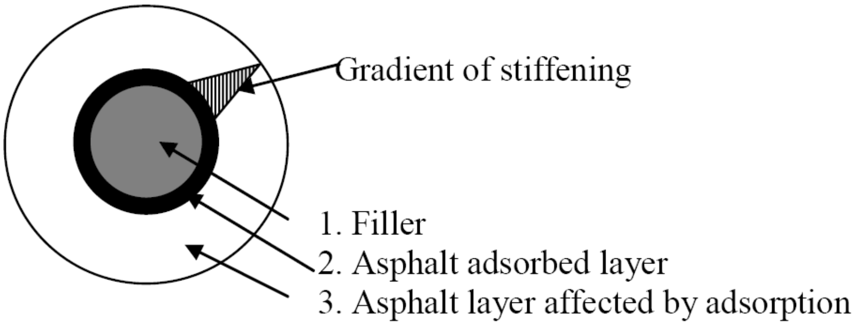

Fig. 3: Fillers' Interaction with Binder after Tunnicliff, 1960 (Source: Bahia, NCHRP 9-45, 2010).

Effect of Mineral Filler on Mastic Properties:

Filler as one of the major components in an asphalt mixture, plays a major role in determing the properties and behavior of the mixture. It plays a major role in both binding and the aggregate interlocking effect (Terrwl and Epps, 1998). The filler has the ability to increase the resistance of particle to move within the mix matrix and/or works as an active material when it interacts with the asphalt cement to change the properties of the mastic (Turunen, 1993). Therefore, selecting proper type of filler in asphalt mixture would improve its properties and thus enhance the mixture performance. The addition of mineral fillers to asphalt binder is known to stiffen the asphalt binder, transforming it in a new material called mastic. This new material is known to affect the workability of the asphalt mix and, therefore, play an important role in the compaction and influence the overall performance of asphalt paving mixtures (Anderson *et al.*, 2001). The mastic influences the lubrication of the larger aggregate particles, and thus affects voids in the mineral aggregate (VMA), compaction characteristics, and optimum asphalt content. During construction of Hot Mix Asphalt (HMA) pavements, the mastic must have enough stiffness to prevent drain-down, or the downward migration of the mastic mainly due to gravitational forces during storage and handling. This is particularly important in open or gap graded mixtures, such as Stone Mastic Asphalt (SMA) mixtures. Finally, the stiffness of the mastic in the field impacts the ability of the mixture to resist permanent deformation at higher temperatures, influences stress development and fatigue resistance at intermediate temperatures, and influences stress development and fracture resistance at low temperatures (Chen, 1996).

The effects of mineral filler in asphalt paving mixtures have been examined extensively in numerous studies. The majority of studies on mineral filler-asphalt systems throughout the century have relied on standard high temperature measurements such as penetration, viscosity, softening point temperature or ductility to describe flow properties and to explain the interaction between asphalt binders and mineral filler.

Early studies (Rigden, 1947, 1954; Heukelom and Wijga, 1971) of fillers in bitumen, measured viscosity of mastics and found that the filler type affected both the temperature susceptibility and the shear dependency of the mastic. Rigden, (1947) conducted a series of experiments to study the relationship between filler properties and the viscosity of mineral filler-asphalt mastics, Rigden showed a strong correlation between the void content of dry compacted filler (the so-called Rigden voids) and the amount of stiffening produced by the filler. Rigden also showed that the voids in the filler at its closest packing are of major importance to the behavior of filler/bitumen systems.

Tunnicliff, (1962) was one of the first researchers to give a comprehensive definition of mineral filler and propose a mechanism for the stiffening of asphalt binders by filler. Tunnicliff proposed that a particle of filler adsorbs a layer of bitumen, which entirely encloses the particle. The adsorbed layer of bitumen assumes a different, stiffer consistency due to the surface energy of attraction between the two materials. The bitumen assumes it's most rigid character immediately adjacent to the particle and as the distance from the particle increases, the forces of surface attraction dissipate until they become negligible and the bitumen retains its original stiffness.

Kallas and Puzinauskas, (1967) believed that filler performed a dual role in asphalt-aggregate mixtures. A portion of the filler with particles larger than the asphalt film will contribute inproducing the contact points between aggregate particles, while the remaining filler is incolloidal suspension in the asphalt binder, resulting in a binder with a stiffer consistency.Kallas and Puzinauskas also found that the stabilities of asphalt mixtures increase up to a certain filler concentration, then decrease with additional filler.

Puzinauskas, (1969) mineral filler play an important role in stabilizing the hot mix asphalt (HMA) by filling the voids within the larger aggregate particles, and improving the consistency of the binder that cements the larger aggregate particles.

Anderson and Goetz, (1973) evaluated the stiffening effect of a series of one-sized fillers ranging in size from 0.6 to 75 mm in one of the first studies that focused on determining the mechanical properties of asphalt filler mixtures. They concluded that both the size of the filler and asphalt binder composition had a significant influence on the stiffening effect. A further study used rheological measurements using a sliding plate viscometer to study the stiffening effect of different fillers, separated into different size fractions. Anderson and Goetz found that not only the size is important, but the mineralogy of the surface also played a role in modifying the rheology of the mastic. The description of physical effects on contact of asphalt film and mineral filler requires the knowledge of the following structural characteristics of fillers to be the most important: grain-size distribution, specific surface area, Rigden voids, as well as grain morphology (sphericity and roundness of grains). Anderson and Goetz also suggested that, reinforcement in asphalt mastics is influenced by particle size of filler, loading time, temperature, and by interactions between asphalt and filler.

Anderson and Goetz, (1973)proposed that the portion of the filler that is suspended in the asphalt stiffens the binder through two mechanisms. A small stiffening effect arises from the volume filling of the filler (i.e. the stiffening caused by the presence of rigid inclusions in a less rigid matrix). Larger stiffening results from the physico-chernical interaction between the asphalt and the surface of the mineral filler.

Anderson, (1982) performed a study on the behavior of the asphalt-filler mastic using the penetration, softening point and ductility. Where by five filler/asphalt (F/A) ratios and five different types of filler were used. These F/A ratios are calculated by volume of material to allow for comparison between filler types. As expected, Anderson found the penetration to decrease with an increase in the F/A ratio. Also, the softening point and viscosities increased with an increasing F/A ratio. The results showed a large increase in the viscosity at an F/A ratio of 0.4. This F/A ratio are lower than those found in many HMA mixtures. The much higher viscosity can affect the compactibility of the HMA and require more compactive effort or higher compaction temperatures.

Based on the Strategic Highway Research Program (SHRP) Idea Project, SHRP AIIR-13 study, Anderson *et al.*, (1992) made several observations as follows:

- A major part of the filler fraction is embedded in the bitumen in such a way that the binder in asphalt mixture is not the pure bitumen but instead a mastic consisting of mineral filler and bitumen.
- The fine fraction of aggregate contributes the majority of the surface area generated by the aggregate.
- The properties of the fine fraction should be dominant in terms of physical-chemical interaction between the binder and mineral aggregate.

In another study, Anderson et al., (1994) stated that some fillers may be added in relatively large quantities with out stiffening the binder. These fillers can extend the binder making the mix appear to have excessive asphalt content. On the other hand, too little mineral filler may reduce the effective viscosity of the mastic and lead to premature rutting of the pavement.

Cooley et al., (1998) used the Superpave binder tests to investigate the stiffening potential of fillers. They verified that the percent bulk volume, one property derived from the modified Rigden’s voids test, can be used to characterize the stiffening potential of fillers. They also recommended that the value of the bulk volume be kept below 55%.

Gubler et al., (1999) conducted Dynamic Shear Rheometer (DSR) and bending beam rheometer (BBR) tests on a series of asphalt binder and filler combinations. Two asphalt binders and three fillers with varied free volumes and ageing conditions were included in the study. The authors believed that stiffening is only one way in which the addition of mineral filler changes the properties of asphalt binder. In fact, mastics behave quite differently than does a binder that is simply stiffer binder. These differences include changes in the material properties with aging and the time and magnitude of loading that are of practical and scientific interest. Unlike asphalt binder, mastics are susceptible to shear; their mechanical properties are changed by the application of stress during the test itself. The study results indicated that filler can promote the oxidation and hardening of asphalt binders. Since it is generally accepted that fatigue is related to hardening of the binder, fatigue must also be related to this phenomenon.

Gubler et al., (1999) have studied the influence of three mineral fillers on the aging mechanism of asphalt binders. Gubler found out that the complex modulus (G*) as well as the phase angle (δ) varied with magnitude and time of loading, thus the mechanical properties of mastics depended not only on the conditions at the time of measurement, but also on sample history prior to the measurement. Therefore fillers might influence the aging of a binder by promoting oxidation or side reactions, such as dehydration or polymerization, fact that leads to a hardening of asphalt mixture.

Wypych, (1999) stated that:filler can be defined as “solid material capable of changing the physical and chemical properties of materials by surface interaction or its lack thereof and by its own physical characteristics”. This definition implies the existence of two ways in which fillers modify a system. Firstly, the ways in which the filler’s shape, particle size and particle size distribution affect the system through filling of the liquid with solid particles. Secondly, the way in which interactions between the solid and liquid phases of the mixture affects the material. The second interactions can vary from strong chemical bonds or physical interactions leading to strongly reinforced materials, to almost no interaction at all.

The effects of varying the filler size and quantity on hot mix asphalt are known to influence the behavior of the hot asphalt mixes (NAPA, 1999). It can stiffen the mix; extend the binder mastic, alter the moisture resistance of the mix; affect the aging characteristics of the mix; and influence the workability and compaction characteristics of the hot asphalt mix (Anderson, 1987).

Kim et al., (2002) describe how the resistance of a mastic to micro-crack development is strongly influenced by the dispersion of mineral filler. Thus, the cohesive strength of the mastic is controlled not by the asphalt cement alone, but by the combination and interaction of the asphalt cement and the mineral filler.

Montepara, A. et al., (2011) evaluate the influence ofbinder and filler type on HMA cracking response. Four different fillers and four asphalt binders, including unmodified and polymer modified binders, were evaluated using a visco-elastic fracture mechanics-based crack growth law. The cracking behavior of mastics was investigated using a modified Direct Tension Test (DTT). Strain localization and damage distribution were observed using a Digital Image Correlation System (DIC) capable of accurately capturing localized or non-uniform stress distributions in asphalt materials. Experimental results indicate that tensile failure properties of the mastic are strictly correlated to HMA failure limits for either unmodified or polymer modified mixtures. It was observed that strain localization and damage distribution in asphalt mixtures is strictly dependent on the physico-chemical interaction between binder and filler and on the particular network established within the mastic.

In summary, the importance of bitumen-filler mastics has been known for over a century and several studies have been carried out with the intention of describing the characteristics of the fillers which best describe the behavior of the resulting mastics. Voids in the filler in its compacted state, referred to as “Rigden Voids”, has consistently been found to be the best single property of the filler which relates to the increase in stiffness, or reduction in flow, of the mastic when filler is added.

Effect of mineral filler on HMA properties and performance:

Mineral fillers are added to asphalt paving mixtures to fill voids in the aggregate and reduce the voids in the mixture. However, addition of mineral fillers has dual purpose when added to asphalt mixtures. A portion of the mineral filler that is finer than the asphalt film thickness mixed with asphalt binder forms a mortar or mastic and contributes to improved stiffening of mix. This modification to the binder that may take place due to addition of mineral fillers could affect asphalt mixture properties such as rutting and cracking. The other portion of fillers larger than the asphalt film thickness behave as a mineral aggregate and serves to fill the voids between aggregate particles, thereby increasing the density and strength of the compacted mixture.

There are many physical and chemical factors that affect the performance of filler in asphalt concrete pavement. Such factors are known to be size and gradation, specific gravity, surface area, shape, voids content and surface characteristics.

Strength and load carrying capacity of HMA is largely the result of the aggregate framework created through particle-particle contact and interlock. Ideally graded, a dense HMA contains successively smaller particles such that the framework created by the larger particles is just filled by the smaller particles. Thus the coarse aggregate framework is filled by the sand-sized material and finally by the mineral filler. However, at some point the smallest particles no longer make contact and, instead, lose contact and become suspended in asphalt binder. These suspended particles do not have the particle-particle contact that is created by the larger particles.

Tunnicliff hypothesized that for dense-graded mixes this loss of particle-particle contact occurred with sizes somewhat less than 75 micron, most likely between 50 and 75 micron depending on the filler and mixture. He further concluded that mineral filler should be defined as the fraction of the aggregate with particles sufficiently small such that the particles are suspended in the asphalt binder and no longer maintain particle-to-particle contact (Anderson et. al, 1996).

Traxler and Miller, (1932) noticed that mixes containing large particles result in more stable mortars than if the large particles are not present. Additional benefits usually result in greater asphalt surface density. In this respect, the success of Portland cement as a filler was believed to be caused partly by its high specific gravity.

Kallas and Puzinauskas, (1962) held that voids in the mineral aggregate (VMA)are affected by several properties of mineral filler, such as particle size distribution, specific surface area, surface characteristics, shape, and effect of filler on the viscosity of asphalt. The found that by changing the concentration of filler up to a certain concentration, stability increase and optimum asphalt content decrease; however as more filler is added, these tend to reverse. They also noticed that in several instances finer materials caused lower mixture viscosity than the coarser fillers at the same concentration level.

In general, filler have various purposes among which, they fill voids and hence reduce optimum asphalt content and increase stability, meet specifications for aggregate gradation, and improve bond between asphalt cement and aggregate (Bouchard, 1992). The use of mineral filler for improving the performance of asphalt concrete mixtures has been repeatedly demonstrated over the years (Anderson, 1973, Tayebali et al., 2000, Little et al., 2005). With regard to fatigue performance, properly selected fillers, which have physico-chemical characteristics compatible with the asphalt binder and aggregate particles, act as bond-strengthening and crack-arresting agents (Little et al. 2005, Craus et al, 1978). Similarly, compatible mineral fillers aid in reducing permanent deformation by increasing the viscosity of the mastic, thus improving the plastic and viscoplastic characteristics of mixtures (Petersen et al., 1987b, Craus et al., 1978, Mohammad 2006).

Ali and Chan, (1996) study the effect of fly ash on the mechanical properties of asphalt mixtures; results from this study indicated that fly ash can be used as a mineral filler to improve resilient modulus characteristics and stripping resistance. The addition of fly ash did not significantly reduce field performance of asphalt concrete mix in terms of rut depth and present serviceability index but increase the amount of surface cracking in the pavement.

Kandhal and Parker, (1998) and Kandhal, (1999) summarized the influences mineral filler can have on the performance of HMA mixtures as follows:

- Depending on the particle size, fines can act as a filler or an extender of asphalt cement binder.In the latercase, an over-rich Hot Mix Asphalt (HMA) mix can lead to flushing andrutting. In many cases, the amount of asphalt cementused must be reduced to prevent a loss of stability orpavement bleeding.
- Some fines have a considerable effect on the asphalt cement, making it act as a much stiffer grade of asphaltcement compared with the neat asphalt cement gradeand, thus, affecting the HMA pavement performanceincluding its fracture behavior.
- Some fines make HMA mixtures susceptible to moisture-induced damage**.** Water sensitivity of onesource of slag baghouse fines has been reported in theUnited States, and the water sensitivity of other stonedusts has been reported in Germany. Stripping of HMAmixtures as related to the properties of filler–asphaltcombinations has been reported in Japan.

Today, it is well recognized that HMA should be considered as mixtures of mastic coated aggregates rather than pure asphalt-coated aggregates. Mastics have been gaining more and more attention in the asphalt industry because of its significant influence on the properties of HMA mixtures and ultimately on the performance of flexible pavements.

In NCHRP Project 4-19, “Aggregate Tests Related to Performance of Asphalt Concrete in Pavements,” Kandhal and Parker conducted DSR tests on filler-asphalt mortars to determine the rutting and fatigue properties. Fines passing a No. 200 sieve (P200 material) obtained from six different mineral aggregates were included in the study. The P200 materials were characterized by Rigden voids, particle size analysis, methylene blue test, and a German filler test. HMA specimens containing different P200 materials were tested in the Superpave shear test device for rutting and fatigue cracking.

AASHTO T283 (modified Lottman test) was used to evaluate moisture susceptibility. It was found that the D60 size (the particle size that 60% would be passing or smaller than) and methylene blue values were related to rutting, whereas the D10 size (the particle size that 10% would be passing or smaller than) and methylene blue values were related to stripping. No performance-related test was identified for fatigue cracking. Laboratory and field-testing have proven that hydrated lime can substantially reduce moisture susceptibility, enhance the asphalt-aggregate bond, and improve the resistance of mixtures to water-induced damage (Little and Epps 2001).

Little and Petersen (2005) recently gave a detailed review of the unique effects of hydrated lime filler on the performance-related properties of asphalt cements (AC).

Sebaaly (2003) updated a work from Little and Epps (2001), where the advantages of hydrated lime in HMA mixtures were analyzed. They suggested that the ability of hydrated lime to improve the resistance of HMA mixtures to moisture damage, oxidative aging, mechanical properties, and fatigue and rutting performances results in approximate savings of $20 per ton of HMA. They also analyzed field data and concluded that hydrated lime increased the average pavement life by approximately 38%.

Huang et al., (2012)investigate the effectiveness of cementitious fillers on moisture susceptibility of HMA mixtures. Five types of cementitious fillers were considered: fly ash, cement kiln dust, and three types of hydrated lime with different finenesses. The test results indicate that the cementitious fillers were generally effective in reducing the moisture susceptibility of HMA mixtures. The finer the hydrated lime particle, the more resistant the asphalt mixtures to moisture induced damage.

Kim et al., (2003) investigated the effect of fillers and binders on the fatigue performance of asphalt mixes. To analyze the effects of fillers, the authors used the theory of viscoelasticity, a continuum damage fatigue model, and a rheological particulate composite model. They concluded that the filler type affected the fatigue behavior of asphalt binders and mastics. Fillers also stiffened the binders, and hydrated lime was more effective in stiffening binders than limestone fillers. Another conclusion was that even if the fillers stiffened the binders, they acted in such a way that they provided better resistance to microcracking and thus an increased fatigue life. Among all the mineral filler used in HMA mixtures, perhaps hydrated lime is the most often investigated because of many benefits associated with its use.

Bahia, H. et al., (2010) conducted a study on test methods and specification criteria for mineral filler, the study concluded that filler characteristics are critical for defining the influence of fillers on mixture performance. Mineral fillers vary significantly in the physical and chemical properties and mineral filler were found to significantly affect mastic and mixture performance indicators and the effects were, in most cases, highly specific to the filler binder combination.

Reyes Ortiz and Alvarez-Lugo (2011)reported that the HMA analyzed were fabricated using a 60-70 penetration asphalt binder, dense-graded aggregate, mineralfiller, and different types and contents of mineralfiller replacements (i.e., lime, cement, and fly ash). The indirect tensile test was conducted to determine both the HMA tensile strength and force-displacement curve, which allowed for the computation of the HMA toughness as well as the energies involved in the process before and after reaching the tensile strength. Corresponding results suggest that the replacement of mineralfiller by cement, lime, and fly ash modified the HMA response in terms of both the tensile strength and energy parameters. In addition, analysis of the energy parameters proved to be useful for determining the optimum mineralfiller content of HMA. Consequently, analysis of these energy parameters can benefit the HMA mixture design process.

Alvarez, A. E. et al., (2012)investigates the filler effect on asphalt-aggregate interfaces of HMA based on thermodynamic properties (i.e., measurements of surface free energy, SFE, performed on asphalts, mastics, and aggregates). Seven asphalts, three different mineralfillers added at different proportions, and six aggregates were assessed. The analysis was conducted in terms of energy parameters computed by using the SFE components of the materials evaluated. Corresponding results suggest that the inclusion of filler in the asphalt led to changes in the resistance to both fracture and moisture damage of the mastic-aggregate systems and the wet ability of the mastic over the aggregate as evaluated in terms of the energy parameters. Since these particular effects are not comprehensively captured based on conventional tests currently used for filler characterization-which mainly evaluate particle size, presence of harmful fines, and morphological properties, the HMA mix design can benefit from characterization of fillers and mastics in terms of the SFE and subsequent computation of the energy parameters.

Summary of Research Related to Mineral Fillers:

Fillers in asphalt are used to obtain increased stiffness or rigidity, reducing creep (permanent deformation), increasing density and lowering the cost of asphalt mixtures. Too much filler in asphalt mixtures can lead to cracking or fatigue problems as the stiffness is increased. Too little filler can lead to “bleeding” of bitumen from the mixture. Much of extensive research studies have been done in the past on the properties of mineral filler and its influence on HMA. In summary, it can be concluded that:

- Mineral filler forms a high-consistency mastic when mixed with asphalt binder, which cements larger aggregate particles together.
- Mineral filler fills the interstices and provides contact points between larger aggregate particles.
- For a given filler type (source), general observation has been made that the finer the filler the greater the stiffening effect; Particle Size Distribution (PSD) data alone is insufficient to predict the behavior of the filler in bitumen.
- Many researchers have shown that the free asphalt correlates well with the stiffening effect produced by a filler measure of packing.
- It is widely believed that depending on the particle size, fines can act as a filler or as an extender of asphalt binder.
- Some fines have a considerable effect on the asphalt binder, making it act as a much stiffer grade of asphalt binder compared with the neat asphalt binder and the degree of stiffening varies significantly between different fillers.
- Although performance varies for different fillers, there are no tests that can adequately predict filler performance.
- Early work indicated that both the size of the filler and the asphalt binder composition had an impact on the stiffening effect.
- The modified Rigden voids (bulk volume concentration) test of mineral filler can be related to the stiffening effect produced when the filler is added to bitumen binder. Fillers that exceed 50 cause the mortar to be excessively stiff and difficult to work (NCAT Report 9-8/2, 1998).
- The viscosity of the neat asphalt increases as much as a 1,000-fold when certain fillers were added to asphalt binder.
- The suitability of filler for use in HMA depends on the properties that are related to the stiffening influence of the mineral fillers.
- Two test procedures emerge as important regarding the effect of mineral fillers on the performance of HMA: the methylene blue test and the dry compacted voids test.

- Numerous studies have evaluated the effects of fines, filler, and mortar on HMA performance in the laboratory and in the field. Mineral fillers largely influence the asphalt mixture performance, depending mostly on their mineralogy (type) and finer size particles. Some fines may also make HMA mixtures more susceptible to moisture induced damage.
- The suitability of filler for use in HMA depends on the properties that are related to the stiffening influence of the mineral fillers.

Efforts to characterize fillers have generally followed three paths:

- *Characterization of Particle Size or Packing:*

Several research studies have been conducted to develop suitable test parameters related to particle size or packing to evaluate the fines and fillers. D60 (the particle size of mineral filler at 60% passing) and methylene blue values were found to be related to rutting, and D10 (the particle size of mineral filler at 10% passing) and methylene blue values to stripping. The modified Rigden voids test has been used to characterize the stiffening potential of baghouse fines.

- *Binder Tests Performed on a Mortar:*

Superpave binder tests, Bending Beam Rheometer (BBR), Dynamic Shear Rheometer (DSR), flexural creep, and direct tension tests have been used by several researchers to characterize the fine mortar or voidless mastics properties.

- *Modeling of the Overall Interaction between the Filler and Binder:*

Recent efforts involve modeling thephysical-chemical interaction between fillers and binder.

Conclusion:

In order to understand the relation between the asphalt properties and mixture properties, it is necessary to define the properties of mineral fillers and filler- asphalt mastics that serve as the binder for the mixture. In this paper the important of the mineral filler and mastic properties in define the mixture performance is reflected in the literature by the huge number of the studies carried out to define the mixture properties and to identify the factor that control them.

The literature review conducted in this article indicated that the most commonly measured filler characteristics can be classified into two categories: physical /geometrical and chemical composition. For each category a number of properties have been found to be important with regard to influence on mastic and/or mixture performance. The physical /geometrical (specific gravity, shape, angularity, and size distribution) as well as chemical (mineral) composition of fillers such as calcium, iron, and aluminum dioxides content can be important variables.

The importance of physical-chemical interaction between the fillers and asphalt has been recognized for a long time and the dependency of mechanical properties of the mastics on the nature of the interaction has been shown in a number studies. Also the majority of the reported studies of mineral filler-asphalt mastics have relied on high temperature routine type measurements such as viscosity, softening point, and penetration to describe flow properties and to explain the interaction between fillers and asphalt binders. With the new testing techniques being developed within the Strategic Highway Research Program (SHRP) for testing of asphalt binders and mastics, a new look at rheology and failure properties of mastics is now possible.

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