

CHAPTER II

LITERATURE REVIEW AND BASIC THEORY

2.1. Literature Review

2.1.1. Optimum crumb rubber content

- **Split Mastic Asphalt**

Stone Matrix Asphalt (SMA) is a coarse graded fracture resistant engineered hot mix asphalt surface layer maximizes coarse aggregate's content in the mix which provides better stone-on-stone contact. Stone mastic asphalt is a delicate balance between the mastic and the aggregate fraction requiring good quality aggregates, consistent grading and careful dosage of mineral fibers to avoid an unstable mix. Additives are generally used in SMA Mix to prevent drain down of binder. During the last few years, SMA has become one of the most popular asphalt pavements in the world (Asmael *et al.*, 2010; Kamaraj *et al.*, 2013; Haininet *et al.*, 2012).

Stone mastic asphalt had its origins in Germany in the late 1960's as an asphalt resistant to damage by studded tires. It is also called split mastic asphalt in German speaking countries and elsewhere may be called split mastic asphalt, grit mastic asphalt or stone matrix asphalt. In Australia it is normally called stone mastic asphalt or SMA for short. Stone mastic asphalt is popular asphalt in Europe for the surfacing of heavily trafficked roads, airfields and harbor areas. SMA was initially adopted from the Germans by Sweden and Denmark, but it is now used extensively in Norway, Finland, Austria, France, Switzerland, and the Netherlands as well (Hainin *et al.*, 2012; Watson *et al.*, 1995).

According to Asmael *et al.* (2010) asphalt pavements in general are facing serious distress problems worldwide. So much has been done to improve the quality of the mix through research and innovations. Stone Matrix Asphalt is gaining popularity worldwide because of the reasons shown in Table 2.1.

Table 2.1: Relative Performance of Stone Mastic Asphalt

Property or Feature	Ranking of SMA Compared to DGA (Dense graded asphalt)
shear resistance	much better
abrasion resistance	much better
Durability	much better
load distribution	Somewhat less
crack resistance	better/much better
skid resistance	Better
water spray	equal/better
light reflection	Better
noise reduction	equal/better
public recognition	much better

Source (Campbell, 1999)

• SMA Gradation

Grading refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because these properties affect the amount of aggregate used as well as cement and water requirements, workability, pump ability, and durability of concrete. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. An example of SMA aggregate gradation is presented in Table 2.2 and Fig 2.1.

Table 2.2: Graduation Requirements for SMA Mixtures

Aggregate Gradation	(% Pass filter)
12.50 mm	100
11.50 mm	90-100
8.00 mm	50-75
5.00 mm	30-50
2.00 mm	20-30
0.71 mm	13-25
0.25 mm	10-20
0.09 mm	8-13

Source (Djakfar *et al.*, 2011)

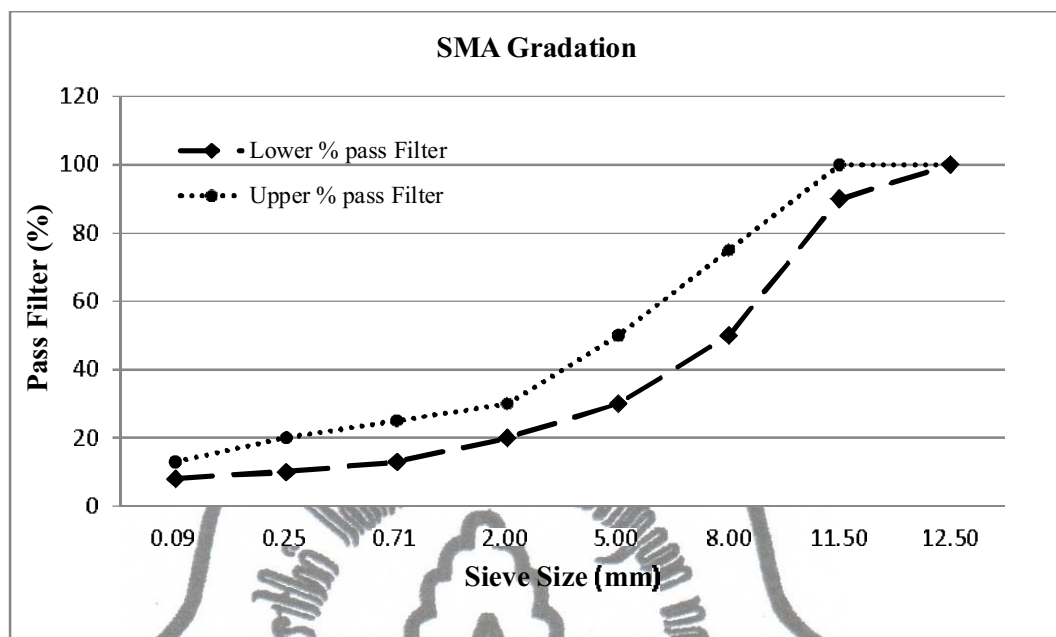


Figure 2.1. SMA Gradation
Source: (Djakfar *et al.*, 2011)

2.1.2 Split mastic asphalt modified with crumb rubber

• Material of Split Mastic Asphalt

A. Bitumen

Bitumen is a black, oily, viscous material that is a naturally-occurring organic byproduct of decomposed organic materials. Also known as asphalt or tar, bitumen was mixed with other materials throughout prehistory and throughout the world for use as a sealant, adhesive, building mortar, incense, and decorative application on pots, buildings, or human skin. The use of bitumen across the world is presented in Table 2.3.



Table 2.3. The properties of bituminous binder and aggregates used for the design of SMA

Property	Countries			
	Germany	Sweden	USA	UK
Type of binder	Low penetration grade	penetration grade	PG grade	50 to 100 mm penetration grade
Course aggregate	100% crushed	100% crushed	100% crushed	100% crushed
Asphalt content	6.5-7.5% by weight mix	6.5-7.5% by weight mix	6.5-7.5% by weight mix	6.5-7.5% by weight mix
Cellulose or mineral filler	0.3 % by weight mix	0.3 % by weight mix	0.3 % by weight mix	0.3 % by weight mix
Mix design	Marshal method of mix design (50 blows on each side)	Marshal method of mix design (50 blows on each side)	Superpave gyratory compactor/ Marshal method of mix design (50 blows on each side)	Marshal method of mix design (50 blows on each side)
Air voids	3% (target)	3%	4%	4%
Surface thickness	25-50, 15-30 and 40	34-43, 38-47	overlays	20-40
Nominal size of aggregate (mm)	5, 11	12, 16	9.5, 16	6, 14
Performance	25% longer life	20% longer life	32% longer life	Extended life

Source: (Prasad, 2013)

The main differences between stone mastic asphalt and bituminous concrete are shown in Table 2.4.

Table 2.4. Main differences of SMA and bituminous concrete

Properties	SMA	BC
Definition	SMA is a gap graded mix which consists of high amount of coarse aggregate firmly bonded together by a strong asphalt matrix. Consisting of fine aggregate, filler, bitumen and stabilizing additives.	BC consists of well graded coarse and fine aggregate, filler and bitumen.
Sample fig.		
Mass of Coarse Aggregate Content, (%)	75 – 80	50-60
Mass of Fine Aggregate (%)	20 – 25	40 – 50
Mass of Filler content,(%)	9 – 13	6 – 10
Binder Type	60/70, PMB- 40	60/70, 80/100 and modified Binders
Minimum binder content by weight of mix, (%)	>6.5	5 – 6
Stabilizing Additives by Weight of mix,(%)	0.3 – 0.5	-----
Air Voids(%) Layer	3—4	3—6
Thickness, mm	25-75	30-65

Source: (Bose et al., 2006)

B. Asphalt Crumb Rubber

Kuennen (2004) stated that asphalt rubber is a technique of mixing asphalt rubber and textured rock taken from the remains of the damaged tires or old. Asphalt has rubber enormous capacity to absorb noise generated by traffic on those roads.

There are different crumb rubber preparation methods. The first method is Ambient grinding, a method of processing where scrap tire rubber is ground or processed at or above ordinary room temperature. Ambient processing is typically required to provide irregularly shaped, torn particles with relatively large surface areas to promote interaction with the asphalt cement.

The second method is cryogenic grinding, a process that uses liquid nitrogen to freeze the scrap tire rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles with relatively small surface area. This method is used to reduce particle size prior to grinding at ambient temperatures.

The third one is granulation method, which produces cubical, uniformly shaped, cut crumb rubber particles with a low surface area. The fourth method is shredding, which process that reduces scrap tires to pieces 6 in.2 (0.023 m²) and smaller prior to granulation or ambient grinding. Rubberized and Conventional Asphalt Noise Test Results Sacramento County Roadway is shown in Table 2.5.

Table 2.5. Rubberized and Conventional Asphalt Noise Test Results Sacramento County Roadways

Roadway	Pavement Type	Duration of Time Elapsed After Paving	Change in Noise Levels, dB Leq
Alta Arden Expressway	Rubberized Asphalt	1 month	-6 dB
		16 months	-5 dB
		6 years	-5 dB
Antelope Road	Rubberized Asphalt	6 months	-4 dB
		5 years	-3 dB
Bond Road	Conventional Asphalt	1 month	- 2 dB
		4 years	0 dB

Source: (RPA Reports, 1999)

This type of asphalt in addition to its role in reducing the noise emanating from the movement of vehicles on the road through the absorption of sound, being a friend of the environment because it is made from recycled materials, and its role in reducing the slides, and its ability to absorb rainwater, thus easing the spread of the spray when it rains, as well as its role in the reduction of maintenance costs due to the long shelf life. It also significantly reduces cost needed for sound barriers.

The earliest application of asphalt rubber was during the 1930s as a joint sealer, in patches and in membranes. The effects of the application of rubber in asphaltic paving material were investigated in the 1950s by the Bureau of Public Records of the State of California using a number of different rubber powders and asphalt combinations (RPA Reports, 1999).

The application of natural rubber by mixing with asphalt materials in roadwork is an alternative material that may help increase domestic consumption of natural rubber. Furthermore, such application could improve the quality of road pavement, extend service life of the road, and reduce expenditures in maintaining road pavement.

Crumb rubber is produced by shredding and grinding scrap tires into very small particles to be used either as asphalt-rubber binders and rubberized asphalt binders in a wet process or as a substitute for a percentage of the fine aggregate in the asphalt concrete paving mixture in a dry method. Depending on the manufacturing method, the properties and applications of the resulting products can vary widely (Bandini, 2011; Hossain *et al.*, 1995).

C. Asphalt-Rubber Process

The asphalt-rubber process is any method that mixes and reacts with the rubber particles with the asphalt cement prior to adding the resulting binder to the aggregate. This process has the longest history of use and is the basis for the Caltrans reduced thickness design. Asphalt-rubber is field blended and requires special equipment at the hot-mix plant to react the crumb rubber with the asphalt cement.

There are two types of processes used to add crumb rubber to liquid asphalt cement:

a) Wet And Dry Mixes

In the wet mix process, rubber and bitumen are digested together at high temperature to produce a crumb rubber binder. The crumb rubber binder is added to aggregate in a mixing plant in the same way as any other binder.

In the dry process, however, dry rubber particles are added to aggregate and bitumen in a pug mill at the asphalt mixing plant. The rubber is usually mixed with the aggregate prior to bitumen addition but is still considered part of the binder. The wet process has the advantage that the binder properties are better controlled, while the dry process is often easier for an asphalt manufacturer to use. To date, the dry process has been mainly used and has produced mixes which have performed successfully in service (APRG, 1999).

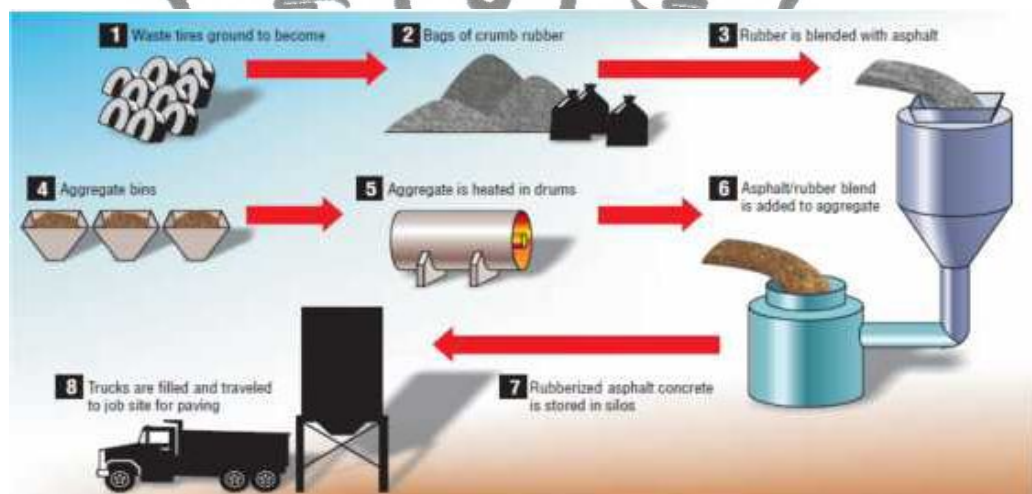


Figure 2.2. Asphalt Rubber, Aggregate Mix Process

Source: (APRG, 1999)

Making asphalt rubber is different from making conventional asphalt. Instead of mixing asphalt cement directly with aggregates, the process first mixes crumb rubber with the asphalt cement. ASTM specifications for asphalt rubber require a crumb rubber content of at least 15 percent. Today, rubber content is frequently boosted to 20 percent.

b) Terminal Blend Process

The terminal blend process digests the crumb rubber into the asphalt cement at the refinery (or asphalt terminal). The terminal blend process does not require special equipment at the hot-mix plant.

The crumb rubber modifier used in asphalt-rubber is in the 10-16 mesh range rubber ranges from 18-22 percent. Terminal blend binders contain 10 percent or less crumb rubber modifier. However, in recent years the crumb rubber modifier content has been increased to 15-20 percent in some projects.

2.2 BASIC THEORY

2.2.1 Optimum crumb rubber content

• Split Mastic Asphalt

Split mastic asphalt or sometimes called Stone Mastic Asphalt is an extreme stone matrix material that can have 30%, or even less, passing the 4.75 mm sieve. Using so little fines would tend to allow segregation of the larger sizes of coarse aggregate. To prevent this, the maximum stone size is limited to between 8 and 12.5 mm. The sand content is so low that the mix is no longer dense graded. This means that air has access to the surface of most aggregate particles.

Split mastic asphalt has found use in Europe, Australia and the United States as a durable asphalt surfacing option for residential streets and highways. SMA has a high coarse aggregate content that interlocks to form a stone skeleton that resist permanent deformation. The stone skeleton is filled with mastic of bitumen and filler to which fibers are added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement.

Split mastic asphalt is a delicate balance between the mastic and the aggregate fraction requiring good quality aggregates, consistent grading and careful dosage of mineral fibers to avoid an unstable mix. Variations in production can alter the mix dramatically, hence the use of additives and/or modified binders. The design philosophy revolves

around developing a strong stone skeleton with a high stone content, high bitumen and mortar content and a binder carrier. Typical parameters are that the coarse aggregate (> 2.36 mm sieve) makes up 70-80% of the aggregate weight, the fine aggregate 12-17% and the filler fraction is in the range 8-13%.

- **SMA Gradation**

Gradation of aggregates is one of the most important factors for the design of SMA Mix. The aggregate gradations used for the mix design may be provided by the Contractor or may be from the actual gradations of the mix design aggregate samples. However, when the mix is to be produced from a plant that returns fines to the mix or the aggregate gradations change during production due to aggregate breakdown, appropriate adjustments shall be made to the mix design gradations. When a mix contains additives and the source of asphalt cement changes from that used in the mix design, tests can be re-done to verify the dosage of such mixes.

After harvesting, aggregate is processed: crushed, screened, and washed to obtain proper cleanliness and gradation. If necessary, a benefaction process such as jigging or heavy media separation can be used to upgrade the quality. Once processed, the aggregates are handled and stored to minimize segregation and degradation and prevent contamination.

Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered include: grading, durability, particle shape and surface texture, abrasion and skid resistance, unit weights and voids, absorption and surface moisture.

- **Asphalt-Rubber**

Asphalt rubber, or rubberized asphalt, is a chemically reacted mix of liquid asphalt binder with 0 to 6% crumb rubber. The rubber is obtained from reclaimed tires, and added to liquid asphalt. It reacted at elevated temperatures prior to being mixed with aggregate.

Rubber produced from the scrap tires, known as crumb/ground rubber, can be used in asphalt mixtures either as a binder modifier (wet process) or as a fine and/or coarse aggregate replacement (dry process). In both wet and dry processes, rubber particles react with bitumen at high temperatures during the manufacturing stage. Compared to the wet process, the reaction time in the dry process is considerably less (maximum six hours) and slower due to the larger particle sizes. Consequently, it is generally assumed that the effect of rubber-bitumen reaction in the dry processed mixture is less and, therefore, has a limited effect on the mixture performance.

2.2.2 Split mastic asphalt modified with crumb rubber

- **Asphalt Damage**

A. Deformation and Fatigue

Permanent deformations, primarily in the form of ruts, are one of the basic asphalt pavement damages impairing its service properties. Application of appropriate asphalt mixtures and binder modification are effective methods for improving asphalt courses resistance. While being manufactured, stored, fitted into a road pavement and during long term service, bitumen binders and asphalt mixtures are subject to continuous unfavorable ageing processes during which pavement courses characteristics change considerably, resistance to permanent deformations being among them (Radziszewski, 2007).

Fatigue failure is the result of flexural cracking of asphalt bound layer. The asphalt layer itself may display a significant amount of permanent deformation in hot climatic conditions. Asphalt pavements can also be damaged by climatic factors such as temperature and moisture. Oxidative aging of asphalt layers is another major cause for concern.

The fracture mechanics approach is one of the major methods to study asphalt fatigue cracking. In this method, the stress intensity factor (SIF), which is calculated from linear elastic fracture mechanics (LEFM), at the crack front tip is used to characterize crack propagation. The SIF uniquely describes the stress concentration condition of the crack tip as the crack progresses.

B. Shear Stiffness and Rutting

Radziszewski (2007) reported that aging causes stiffness to a greater extent in case of mixtures with unmodified binders than in case of mixtures with elastomer or rubberized bitumen binders. The accumulation of permanent deformation with an increasing number of loading cycles under repetitive shear loading follows an almost linear behavior on a log-log scale. Rutting is also the manifestation of permanent deformation in different layers of the pavement

When rubber content of asphalt blend increases, both the shear modulus and damping ratio of the material increase. Additionally, the shear module and damping ratios are strongly correlated to changes in temperature. The shear modulus and pressure are related as well, with the stiffness decreasing slightly as the confining pressure is increased; however, temperature effects tend to dominate the behavior of all of the asphalt mixes.

Radziszewski (2007) stated that ruts are most dangerous because they might cause vehicles to skid during precipitation. Rut forming is connected with the process of accumulation of deformations of asphalt courses of the pavement resulting from frequent dynamic loads.

Shear stiffness correlates best with rutting. An average value of the maximum shear stress could be calculated as the product of the shear stiffness and the maximum strain. The maximum shear stress value represents a uniform shear stress distributed over the total area of failure of the pavement sample, assuming the linear relationship between the torsion and angular displacement is valid until failure.

C. Asphalt Noise

In recent years, environmental noise has become a serious issue for civil infrastructure and environmental administration due to public concern over the subject of noise pollution. The most significant deterioration of environmental acoustics conditions comes from road traffic transportation, particularly in built-up areas. In addition, the volume of road traffic has increased significantly in the last few decades and at present gives a contribution. Measures like the renewal of road surfaces with different types of

noise reducing pavements or the replacement of rough pavements by smoother layers should be taken.

- **Asphalt Damage Tests**

Different methods can be used to test mechanical properties of Stone Mastic Asphalt. Ibrahim et al.(2006) compared SMA mixtures and conventional dense graded asphalt mixtures on the basis of laboratory performance testing which included Marshall stability, loss of Marshall stability, indirect tensile strength, loss of indirect tensile strength, resilient modulus, fatigue and rutting. Optimum Binder contents were 5.3% for control mixes and 6.9% for SMA mixtures, 0.3% mineral fibers by weight of mixture was used to avoid draindown of excess asphalt. SMA mix proved its superiority over the conventional mixes showing better resilience, rutting resistance and durability. The following are some discussions about the commonly used tests.

A. Indirect Tensile Stiffness Method (ITSM) and Indirect Tensile Test (ITS)

The stiffness modulus is an important performance indicator for asphalt mixtures especially the binder and base layers. The elastic stiffness in a pavement is a measure of the material's ability to spread the traffic loading over an area. A mixture with high elastic stiffness spreads load over a wider area which reduces the level of strain experienced lower down in the pavement structure, dependent upon the temperature and frequency of loading. The stiffness of a bituminous material can be used in the calculation of required layer thickness in pavement design.

The Indirect Tension Test (IDT) is frequently used in civil engineering because of its benefits over direct tension testing. Indirect tensile tests are often used in laboratory characterization of bituminous mixtures. The indirect tensile test is used to evaluate the stiffness modulus of test specimens prepared in laboratory, by compacting materials into suitable cylindrical moulds, or cored from compacted bituminous layers of pavements. For asphalt mixtures, the Indirect Tension Tester (IDT) is used to perform creep and strength tests on cylindrical specimens loaded in compression along the diameter.

During Indirect Tensile Strength Testing by Khan and Kamal (2012), High values of Resilient Modulus were observed in case of Superpave mixes. Even at maximum testing temperature (55°C), Superpave mix performed better than the other two mixes.

B. Marshall Character

The Marshall test method is used for determining the optimum bitumen and optimum waste crumb rubber content of split mastic asphalt. Study by West and Moore (2006) determined a compactive effort for Stone Mastic Asphalt (SMA) mixes with the Superpave gyratory compactor (SGC) that would match a 50-blow Marshall compactive effort using aggregates and mix designs common in Georgia. SMA mix designs were prepared with five aggregate sources using a 50-blow Marshall compaction and 50, 75, and 100 gyrations with an SGC. Optimum asphalt contents from the mix designs were compared. Aggregate breakdown from each of the compactive efforts was analyzed. Laboratory rutting tests were conducted on each mix design using the Asphalt Pavement Analyzer (APA). The results of the laboratory mix designs indicated that 35 gyrations in the SGC, on average, provided the same density as Marshall compaction.

C. Unconfined Compressive Stress and Creep Test

Creep is high temperature progressive deformation at constant stress. "High temperature" is a relative term dependent upon the materials involved. Creep rates are used in evaluating materials for boilers, gas turbines, jet engines, ovens, or any application that involves high temperatures under load. Understanding high temperature behavior of metals is useful in designing failure resistant systems.

The creep test (unconfined or confined) has been used to estimate the rutting potential of HMA mixtures. This test is conducted by applying a static load to a HMA specimen and measuring the resulting permanent deformation.

Extensive studies using the unconfined creep test (also known as simple creep test or uniaxial creep test) as a basis of predicting permanent deformation in HMA has been conducted. It has been found that the creep test must be performed at relatively low stress levels (cannot usually exceed 30 psi (206.9 kPa)) and low temperature (cannot

usually exceed 104°F (40°C)), otherwise the sample fails prematurely (Brown *et al.*, 2001).

A creep test involves a tensile specimen under a constant load maintained at a constant temperature. Measurements of strain are then recorded over a period of time. Good fracture properties are an essential requirement for asphalt pavements for which the prevailing failure mode is cracking due to low-temperature shrinkage stresses. Creep tests can be performed on asphalt binder and asphalt mixture specimens. Based on the elastic solution for a simple supported beam and the correspondence principle that relates the governing field equations of elasticity and the Laplace transforms with respect to time of the basic viscoelastic field equations, the creep compliance is obtained. The final results are reported in the form of a plot of the inverse of the creep compliance, used as surrogate stiffness, versus time.

The stiffness (S) and the m-value, which represents the slope of the log stiffness as a function of log time, are used to determine a critical temperature value based on limiting the stiffness obtained at 60 seconds to values lower than 300MPa and the m-value obtained at 60 sec to values higher than 0.300.

• Performance Index

The terms performance management and individual performance indicators are often used by many road agencies in their road assessment systems to report road network service levels and expected performance targets given annual investment allocations. Some performance indicators provide road agencies with information on pavement structural condition evaluation, while other performance indicators give a sense of pavement functionality on road safety and serviceability level.

The key performance indicators used in Ministry of Transportation of Ontario (MTO) PMS include International Roughness Index (IRI), Riding Comfort Index (RCI), Distress Manifestation Index (DMI), and Pavement Condition Index (PCI). Each of the indicators has an important role in not only assessment of specific pavement functional or structural condition, but also in economic analysis of pavement maintenance and rehabilitation strategies and allocation of investments. When applied in road asset

management, these performance indicators are used to establish the trigger levels relating to road service standards technically and economically. For more than 30 years, the ministry has been collecting pavement condition information for feeding MTO PMS applications on all provincial highways at network level.

2.3. Hypothesis

The hypothesis of this research is:

H₀: The addition of crumb rubber as optimum modifier of Stone Mastic Asphalt will not have any effect on the Marshal properties, ITS, ITSM and UCS values of SMA.

