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ASSESSMENT OF STONE MASTIC ASPHALT COMPRISING WASTE MODIFIERS

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Master's Thesis

Supervisor
Asst. Prof. Dr. Mohsen SEYEDİ

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The thesis titled “Assessment of stone mastic asphalt comprising waste modifiers” prepared by SHIREEN SULAIMAN MOHAMMED NASER has been accepted by the majority of votes for the degree of Master of Science thesis in civil engineering.

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Signature

DEDICATION

I am honoured to dedicate my master's thesis to (my family) as a way of showing my gratitude for your unwavering support and inspiration during this process. Without your assistance, I would not have been able to get to this point. Your mentoring and advice have been of the utmost value to me.

I'm grateful for everything.

PREFACE

This thesis is the culmination of several years of study and research and represents the most significant academic work I have undertaken thus far. It has been a challenging yet rewarding journey, and I am grateful for the opportunity to share my findings with others. The purpose of this thesis is to *Assessment of stone mastic asphalt comprising waste modifiers*. I have been fortunate to receive guidance and support from many individuals. I would like to express my gratitude to my supervisor Asst. Prof. Dr. Mohsen Seyedi, for their unwavering support and guidance. Their expertise and insights have been invaluable to me, and I am grateful for their mentorship. I would also like to thank my family for their encouragement, feedback, and advice. Their contributions have helped me to shape my ideas and refine my research. Finally, I would like to acknowledge the participants who took part in this study. Without their willingness to share their experiences and perspectives, this research would not have been possible.

It is my hope that this thesis will contribute to the field of civil engineering and will provide a foundation for future research in this area. Thank you for taking the time to read this work.

ABSTRACT

ASSESSMENT OF STONE MASTIC ASPHALT COMPRISING WASTE MODIFIERS

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Recently, there has been interest in stone mastic asphalt from both industry and research. It is a gap-graded combination with a significant amount of asphalt, stabilisers made of fibres or polymers, and coarse particles. The higher number of stone-to-stone interactions and interlocking in the mix caused by the high concentration of coarse aggregate both add to the material's greater strength. Furthermore, the strong mortar binder makes a substantial contribution to the material's extended lifespan. In SMA mixtures, stabilising ingredients are frequently included to prevent the mixture from drain down. On the other hand, field and laboratory studies conducted over the past few decades have demonstrated that dry mixed fibre additive asphalt mixtures function wildly inconsistently in the wet process. According to recent research, the internal structure and phase components of an asphalt mix affect how well it performs. This research aims to develop a sustainable process for the SMA-incorporated by adding paper pulp with CKD through the dry process. This procedure examines the attributes related to volumetric features like Air voids (AV), bulk density (BD), void filled in asphalt (VMA), void Fill aggregate (VFA), and Drain Down Test (DRT) as well as properties linked to mechanical characteristics such as the Marshall Stability Test (MS) and Marshall Flow Test (MF), indirect tensile strength, and skid resistance. The SMA was improved by adding modifications to the mixture, namely paper pulp fibre, CKD, and emulsion, in a novel process in fixed proportions where the modifier is added directly to the aggregate sample in five different proportions: 0.2%, 0.4%, 0.6%, 0.8%, and 1% of the total SMA mix by dry method. The results were as follows: drain down decreases to virtually zero in the expected temperature as well as the anticipated temperature +15 degrees accordingly.

Marshall stability increases by 6.7%, 11%, 22%, 33%, and 20% with 0.2%, 0.4%, 0.6%, 0.8%, and 1% EPC modifications, respectively. The use modifiers are due to the increase in tensile strength (ITS), with the greatest being 0.8% EPC. When SMA0.2, SMA0.4, SMA0.6, SMA0.8, and SMA1% were used in any of the modified SMA mixtures, the surface skid resistance of the mixture increased significantly by approximately 40%, 22%, 13%, 31%, and 35%, respectively, in the dry condition. This was the case across all of the modified SMA mixtures. When the surface of the mixture is wet, the resistance to skidding is increased by about 26%, 38%, 21%, 22 %, and 17%, respectively. The test of the TSR improves by 19%, 16.7%, 7.15% and 6% when 0.2%, 0.4%, 0.6%, and 1% EPC are used to modify the SMA mixture.

Keywords: Stone Mastic, Asphalt, Waste Modifiers, SMA, EPC.

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ABBREVIATIONS

AMBS	Activated Mineral Binder Surface
CM	Control Mixture
CMF	Conventional Mineral Filler
DGA	Dense Graded Asphalt
DRT	Drain Down Test
DS	Dynamic Stability
SMA	Stone Mastic Asphalt
GCA	Bulk Specific Gravity Of Coarse Aggregate Fraction
Gmb	Bulk Specific Gravity Of Compacted Mixture
Gmm	Maximum Theoretical Specific Gravity
MB	Modified Binder
MD	Mixed Dosage
MMS	Modified Mixtures
NB	Neat Binder

1. INTRODUCTION

1.1 BACKGROUND

Stone mastic asphalt (SMA) is an asphalt blend recognized for its significant resistance to deformation, wear, cracking and skidding, making it suitable for heavily trafficked roads1. SMA is composed of a gap-graded aggregate skeleton that is bonded by a mastic mortar, which consists of asphalt binder, filler and fiber2. The mastic helps to prevent the binder from draining and provides durability and stability to the mixture3. SMA, which has been utilized in Europe for approximately four decades, was initially developed to resist abrasions caused by studded tires [41]. Its application persisted even post the studded tire prohibition, as SMA demonstrated outstanding resistance to deformation under heavy traffic and elevated temperatures. SMA is characterized as a mixture with gaps comprising 70–80% of the aggregate being coarse of the entire mass of the aggregate, 6-7% binder, and 8–12% filler, and approximately modifier 0.3-0.5%. The substantial presence of coarse-grained material in the mix forms a skeletal structure, enhancing stone-to-stone contact and providing robust resistance to rutting. According to [9], Instead of fine aggregate asphalt mortar, coarse aggregate particles support the loads of traffic in SMA. The modifier functions to retain the binder in the mixture at high temperatures. For high-volume roads, SMA has shown to be more economical than dense graded mixes. [14] acknowledges that various factors influence SMA performance, including variations in the source and grade of the binder, aggregate kinds and environmental factors, production methods, and construction procedures. Fig. 1.1 shown the Stone Mastic cross-sectional view.

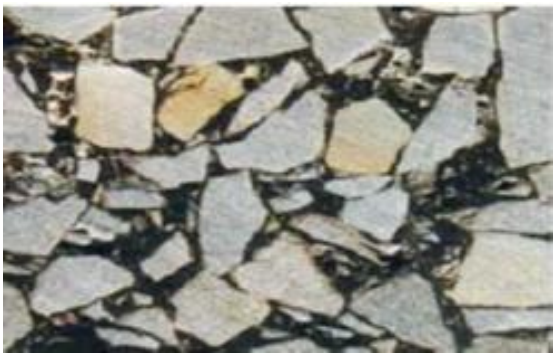


Figure 1.1: Depicts the Cross-Sectional View of Stone Mastic.

1.2 PROBLEM STATEMENT

SMA is a widely used asphalt mixture for road pavement, but it requires a large amount of asphalt binder, filler and fibre, which increases the cost and environmental impact of asphalt production. Moreover, SMA is susceptible to moisture damage and aging, which reduces its performance and durability. Therefore, there is a need to find alternative materials that can improve the properties of SMA mixtures and reduce the consumption of natural resources and energy. CKD and waste papers are two categories of waste materials that can be used as modifiers in SMA mixtures, but their effects on the performance of SMA mixtures are not well understood. The aim of this study is to investigate the viability and advantages of incorporating CKD and waste papers as modifiers in SMA mixtures, comparing them to conventional SMA mixtures. The study will utilize laboratory tests and field trials to assess the characteristics of SMA mixtures containing CKD and waste papers, such as stiffness, rutting resistance, fatigue resistance, moisture susceptibility and skid resistance. The study will also analyse the economic and environmental aspects of using CKD and waste papers in SMA mixtures, such as cost, energy consumption, greenhouse gas emissions and waste reduction. The study will address the following research questions:

a. How do CKD and waste papers affect the workability, stability and durability of SMA mixtures?
b. How do Cement Kiln Dust (CKD) and waste papers impact the performance of SMA mixtures under varied loading and environmental circumstances?
c. What are the optimal proportions of CKD and waste papers to be used in SMA mixtures?
d. What are the economic and environmental benefits of using CKD and waste papers in SMA mixtures?

1.3 THE RESEARCH OBJECTIVE

This study seeks to enhance and optimize the mechanical and durability attributes of Stone Matrix Asphalt (SMA) with the objective of extending the mixture's service life and improving its resistance to sidewalk rutting, wet weather skid and cracking. Through the implementation of a sustainable approach. The methodology involves employing cost-effective waste materials through an innovative dry process, departing from traditional wet methods. The specific objectives include:

a. Experimentally showing that the novel dry process approach could be used to successfully incorporate wastepaper and CKD into the production of SMA by using a modified aggregate grade distribution has resulted in the development of an inventive production technique.
b. In adherence to the sustainability principle, the selection of asphalt modification for SMA mixtures involved opting for locally abundant and cost-effective waste materials, namely cement kiln dust (CKD) and wastepaper fibre.
c. Detailing the characteristics of both unmodified and modified SMA mixes with respect to:

   a. Indirect Tensile Strength Test (ITS), Marshall Stability (MS), Marshall Flow (MF), and Skid Resistance (SR) are examples of mechanical tests.
   b. Durability tests, specifically Tensile Strength Ratio (TSR)

d. Conducting a comprehensive comparison of the durability, mechanical, and volumetric characteristics of the newly formulated SMA mixture with standard SMA mixes. This comparison aims to validate the practicality and efficacy of the developed SMA mixture.

1.4 THE SCOPE

The research scope is outlined as follows:

a. Local sourcing of all materials for the study, comprising two filler types, one aggregate type and gradation, and a particular asphalt type (40–50).
b. Exclusively laboratory-based testing procedures are employed in this research; no field tests are conducted. The tests are performed at the University of Kerbela's highway laboratory.
c. The novel process involves preparing granules and adding them as a dry modifier. These granules include specific groups of paper pulp, CKD, bitumen emulsion, and thinner.

1.5 THEIS ORGANIZATION

The structure of this thesis comprises five chapters, with each chapter presenting the respective outcomes of the study as follows:

a. Chapter Two: Literature Review

An exploration of the existing body of knowledge concerning SMA mixtures, encompassing their characteristics, efficacy, and failure-resistant nature.

b. Chapter Three: Materials and Methodology.

This section offers an overview of the materials utilized in formulating SMA mixtures, outlines the laboratory tests performed, and details the methodology followed during this study.

c. Chapter Four: Results and Analysis

Summarizing the outcomes of laboratory tests and offering a comprehensive analysis and interpretation of the SMA mix results, both modified and unmodified.

d. Chapter Five: Conclusions and Recommendations

This chapter summarizes the study's findings and offers suggestions for further research projects.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The need for pavements that can withstand rutting, cracking, and other damages from heavy traffic and studded tires is acknowledged by the asphalt industry. Roadway pavement contractors Devised the Stone Mastic Asphalt (SMA) mixture, originally proposed in Germany, to address this requirement.

The gap-graded composition of Stone Mastic Asphalt (SMA), marked by a substantial proportion of coarse aggregate (>70%), promotes increased stone contact, creating a sturdy network for efficient load classification. In this chapter conducts a literature review on SMA, delving into its properties, applications, typical components used in mix design, and the incorporation of recycled materials in asphalt binder modification. The discussion also encompasses performance metrics for SMA mixtures and concludes with an examination of SMA's resilience to various types of failure.

2.2 ADAPTABLE PAVEMENTS

Since the entire pavement structure is flexible, flexible pavements are referred to as such. Due to traffic loads, something "bends" or "deflects." This "flexing" can be accommodated by the pavement construction, which is often made up of numerous layers of materials. With this kind of Material layers of pavements are typically organized in descending load order. bearing capacity using the most expensive and highest load-bearing material top and least expensive material (and one with the lowest load-bearing capacity) on the bottom. The pavement's stiffest and largest contributor is the surface course. Even though the lower layers are less rigid, they play a vital role in drainage, frost protection, and overall pavement strength. A conventional flexible pavement system comprises the surface course, base course, and optionally, the subbase course (refer to Fig. 2.1). The surface course, the uppermost layer subjected to traffic loads, delivers essential characteristics including drainage, resistance to rutting, noise mitigation, smoothness, friction, and noise control. Additionally, it plays a vital role in preventing excessive surface water from infiltrating the underlying base, subbase, and subgrade courses. The wearing course is the highest layer of the surface course that directly contacts traffic loads. When this is worn out or damaged, it can be taken out and replaced. Before difficulty spreads to the underlying intermediate or binder course, the wearing course can be rehabbed. This layer, which makes up the majority of the surface course, is intended to disperse the weight that is applied to it. The base course, positioned directly beneath the surface course and responsible for transmitting loads to the subgrade, is commonly composed of stabilized or unsterilized aggregate. Bituminous mixtures such as hot mix asphalt can serve as the base course. Optionally, a layer of lower-quality, more economical material may be utilized as a subbase course above the subgrade and beneath the base course. In many situations, the inclusion of a subbase course is not essential.

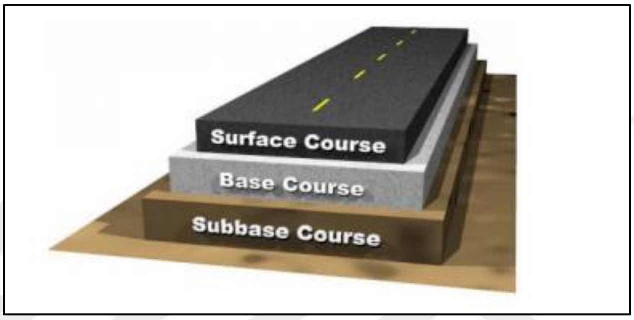


Figure 2.1: Fundamental Structure of Flexible Pavement.

2.3 BITUMINOUS MIXTURES CATEGORIZATION

A bituminous mixture is made up of additives, suitably graded aggregates, and bituminous materials (as binders). Bituminous mixtures used in pavement applications can be categorised based on their production processes or by their makeup and properties.

Bituminous mixes can be divided into three categories: Stone Matrix Asphalt (SMA), Open-Graded HMA, and Dense-Graded HMA based on their composition techniques and characteristics. After placement and compaction, dense-graded mixtures (see Fig. 2.2 a) exhibit relatively few air gaps and a gradation of aggregates that is evenly distributed from coarse to fine. These mixtures are commonly used in bituminous pavements for surface and binder courses. A high-quality, dense-graded HMA mixture is often referred to as bituminous concrete. A mix is referred to as a sand mix if all of the aggregate particles pass through the 9.5 mm screen, and as a large stone dense-graded HMA mix if the maximum aggregate size is greater than 25 mm.

On the contrary, an open-graded Hot Mix Asphalt (HMA) mixture (refer to Fig. 2.2 b) comprises notably larger aggregates with minimal or no fine particles, intentionally designed to allow water permeation. These mixes possess a significantly lower bitumen concentration compared to dense-graded HMA mixes, attributed to the reduced aggregate surface area. Stone Matrix Asphalt (SMA), depicted in Fig. 2.2 c, is a bituminous mixture with a gap-graded composition, featuring a substantial proportion of filler and coarse aggregates and a minimal number of medium aggregates. When placed, SMA demonstrates a high macro texture, low air voids, and binder content, contributing to effective surface drainage and waterproofing.

a. Dense graded b. Open graded c. Stone Matrix

Figure 2.2: A Bituminous Mixture.

In Fig. 2.3, a view of A standard Stone Matrix Asphalt (SMA). A comparison is drawn between the composition of a typical Stone Mastic Asphalt (SMA) mixture and a standard Dense Graded Mixture [30]. In contrast to the conventional Hot Mix Asphalt (HMA) structure on the right, which is distinguished by a uniform aggregate gradation and lower bitumen binder content, the cores from SMA mixtures on the left showcase a higher percentage of fractured aggregate and a greater proportion of bitumen binder.

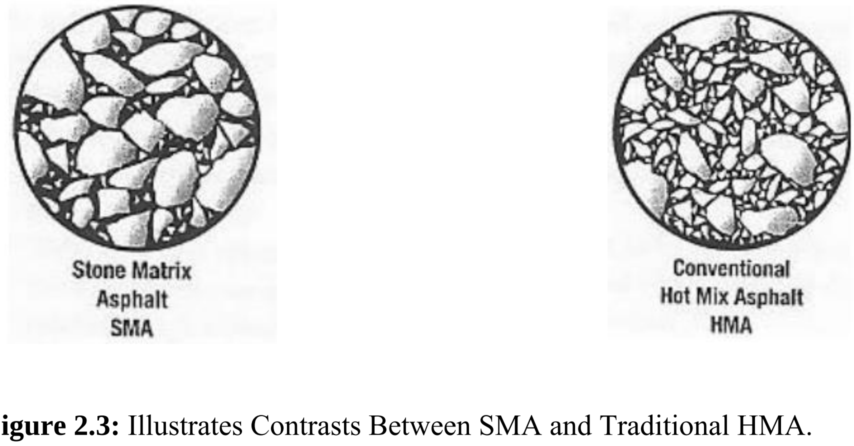


Figure 2.3: Illustrates Contrasts Between SMA and Traditional HMA.

2.4 OVERVIEW OF STONE MASTIC ASPHALT (SMA) AND ITS PROPERTIES

The ingredients of Stone Matrix Asphalt (SMA) are asphalt, fiber stabilizer, fine and coarse aggregate, and mineral powder. It is distinguished by a high concentration of mineral powder and coarse aggregate, a sizable amount of asphalt, and a low percentage of intermediate particles. By filling in the spaces left by the coarse aggregate skeleton, the asphalt produces a dense structure. Many aggregates come into direct contact with one another and tightly interlock to form this skeleton, which is capable of supporting large loads. Furthermore, the combination of mineral powder and asphalt produces a mastic with a high bonding strength, improving the SMA's overall mechanical qualities.

Strong skeleton and high-strength mastic work together to give SMA significant vertical and lateral restraint and the ability to withstand long-term deformation under vehicle loads. SMA's positive qualities such as strong temperature stability, superior skid resistance, durability, and resistance to rutting make it a popular choice for asphalt road construction.

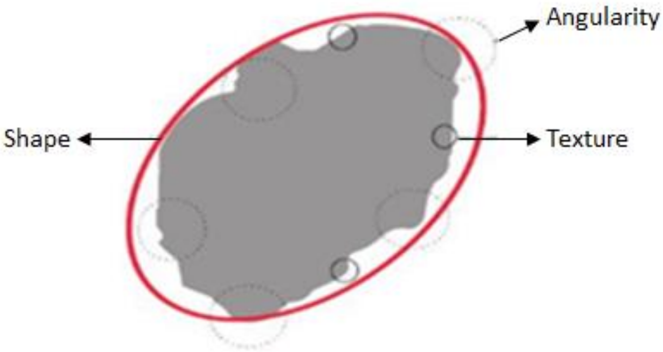
2.5 INGREDIENTS IN SMA MIXES

2.5.1 Aggregate

Since aggregate characteristics Constituting approximately 85% of the volume of the Hot Mix Asphalt (HMA) mixture, they exert a significant influence on both Stone Mastic Asphalt (SMA) and HMA overall. As a necessary result of mistakes or deviations that happened during the SMA's design, production, or assembly. These characteristics include gradation, roughness, and angularity (form), for instance. The grades utilized in SMA combinations and their impact on the morphological properties of aggregates are depicted in Fig. 2.4.

a. angular aggregates

b. sub-round aggregates



c shape characterization

Figure 2.4: Components in SMA Mixes Aggregates.

The SMA aggregate structure's stability is intimately related to the resistance of asphalt pavements to rutting under traffic and environmental conditions. According to the Strategic Highway Research Programmed (SHRP), two of the most crucial aspects affecting the stability of HMA are aggregate features, including gradation and form [32]. Improvements in fracture resistance, shear strength, and effective loading patterns that can tolerate heavy traffic are among the results [23]. The coarse aggregates' form in SMA, The pivotal factor affecting the mechanical performance of SMA mixtures has been found to be their texture, elongation ratio, angularity, sphericity, and flatness ratio [1],[40]. Polyhedral cubic particles help the employed aggregate withstand permanent deformation while also enhancing its ability to provide low internal friction. The mechanical qualities of the aggregate structure are impacted by the interlock and disintegration of the aggregate particles, which are reduced by flat and elongated aggregates [11]. As a result, due to their capacity to provide aggregate particles with interlock, more common aggregates are utilized in the design of asphalt mixtures the more angular the aggregates. mixtures of asphalt with angular particles exhibit greater shear resistance compared to those without angular particles. The rough surfaces of these aggregates promote interaction at the particle-asphalt binder interface, addressing or reducing concerns linked to the fatigue and work ability characteristics of asphalt mixtures [8]. Furthermore, as indicated by [19], sharp and angular aggregate particles are preferred over flat-elongated aggregates.

Drawing from the results of laboratory performance tests conducted on eight different types of Stone Mastic Asphalt (SMA) combinations, [23] examined the morphological alterations that occurred in coarse aggregates. It was discovered that the qualities of coarse particles significantly improve the mixture's resistance to wear and ruts, careful morphological selection, and wear resistance. As suggested by [10] and [27], the aggregates employed in SMA mixtures should possess the following qualities:

a. A rough texture and a highly cubic shape that inhibit rutting and movement.
b. Resistance to breaking easily under high traffic loads.
c. Remarkably strong resistance to polishing
d. Robust resistance to abrasion

Another important factor that affects how well an asphalt mixture performs is the gradation of the material. This feature of aggregate gradation is essential for the volumetric properties and functionality of the asphalt mixture. It is well accepted that the gradation of the aggregate impacts attributes such as moisture sensitivity, fatigue resistance, skid resistance, permeability, durability, stiffness, and stability (Kandhal & Cooley, n.d.) .

The optimal gradation can be challenging to determine because it requires a complex estimating process that depends on the loading, environmental factors, mix properties, and the pavement section where it will be applied [18]. When calculating SMA thickness, it's also crucial to take the NMAS (more than 10% of the aggregate material retained by a sieve size larger than the first) into account. In HMAs, the maximum aggregate size and the material's resistance to permanent deformation are directly correlated. It's fascinating how NMAS affects SMA mixtures. [41] provided a summary of the results of a laboratory test on Wear Stone Mastic Asphalt Road surface material. They discovered that, when we use the test of roading machine, the (14-10) mm Stone Mastic Asphalt performed likewise. The primary difference is SMA14's ability to produce more complex macrotextures. The key difference lies in SMA14's capability to generate more intricate macrotextures.

2.5.2 Asphalt Binder

The performance of a pavement is significantly influenced by the elasticise asphalt binder, which is the sole part of a pavement that can be deformed. Because bitumen can bind and adhere to aggregates well, it has historically been used for paving [35] . It is a highly complex organic substance made up of numerous different types of molecules, both polar and non-polar, and it exhibits exceptional elasticise qualities. The colloidal system known as asphalt binder is created when the molecules maltene and asphaltene, each of which has a distinct molecular weight, are joined. The material known as "asphaltene," which has a large molecular weight, is dispersed by the component known as maltene and is composed of Hydrocarbons with low molecular weight, including saturates (paraffin), aromatics, and resins. The polar component of asphalt, asphaltene, is crucial to its chemical composition, which in turn regulates the asphalt's rheological and durability features. The foundation of asphalt is made up of asphaltene, which produces an electric body with low molecular weight compounds at the edges and high molecular weight compounds in the middle. Asphaltene can be found in resins as well as maltene. Fig. 2.5 describes the composition of asphalt and the various forms it can take.

The two different types of formations that make up asphalt are referred to as "Sol and Gel" [31].

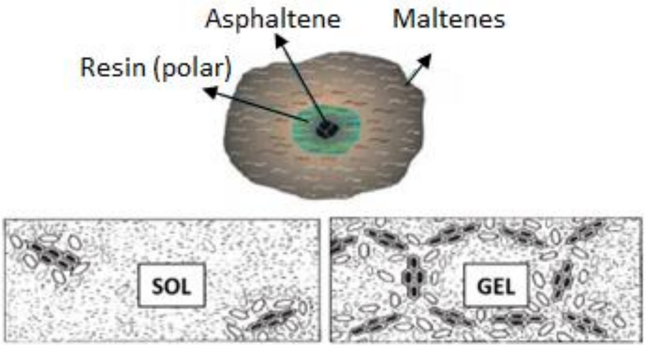
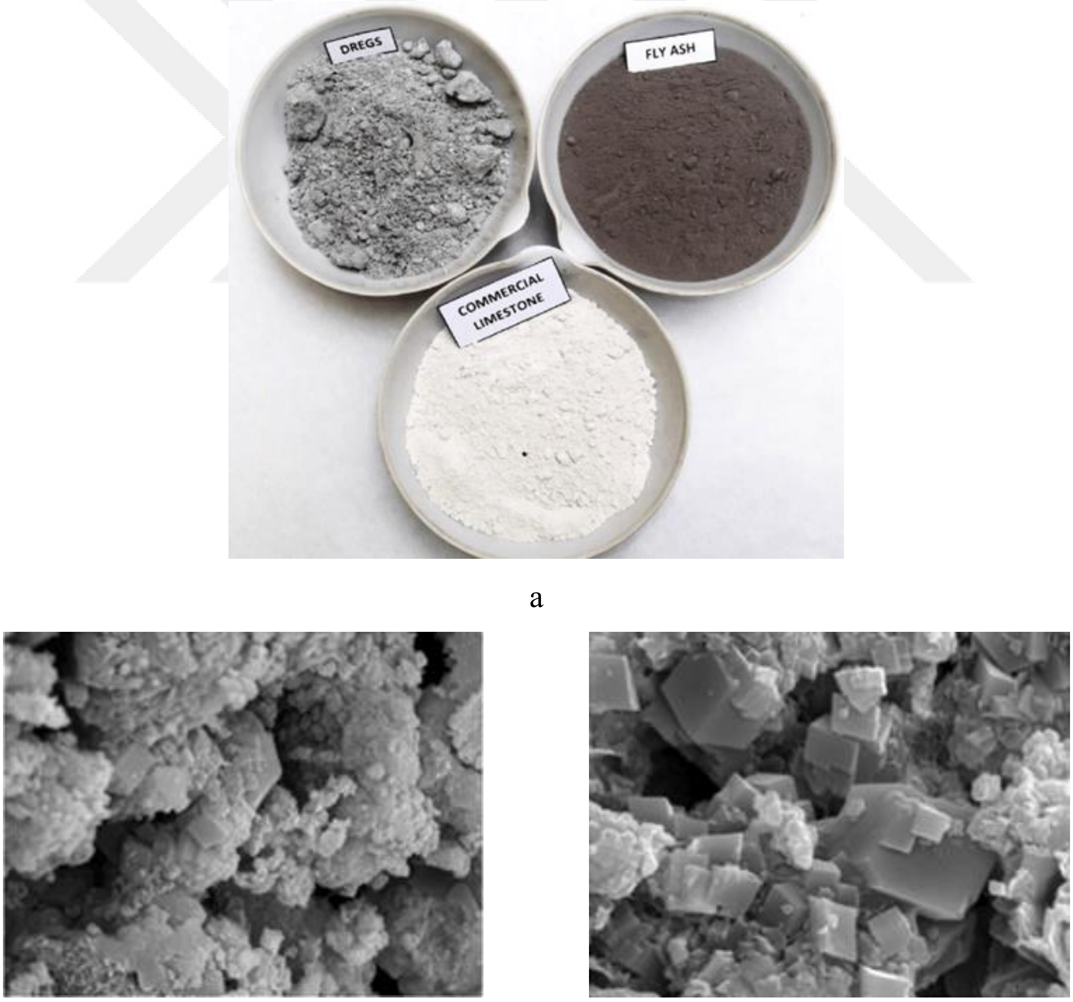


Figure 2.5: A Diagram Displaying the Asphalt Structure's SOL and GEL.

In SMA mixtures, bitumen serves as a binder to keep the aggregates, filler, and stabilizers together. SMA combinations have a longer lifespan due to the high concentration of mortar binder in the mixture. Temperature, elasticize, and the ageing sensitivity of the bitumen all have an impact on how bituminous mixes behave. The performance of bitumen is influenced by both loading time and temperature. Lower temperatures and shorter loading times can lead to stiffening. Since bitumen is since bitumen displays both viscous and elastic properties under typical side-walk temperatures, it should be regarded as a elasticize. At low temperatures, it functions as an elastic material, and at high temperatures, it transforms into a viscous fluid. In 2014, [3],[36], SMA mixtures are made using significant amounts of asphalt, sometimes up to 8%. Due of their high asphalt concentration and coarse aggregate skeleton, these combinations are especially vulnerable to drain down problems [13]. Asphalt pavements also confront a new set of difficulties when traffic volumes and speeds increase, including rutting, fatigue, temperature sensitivity, and ageing. Bitumen's tendency to absorb solar energy and raise interior temperatures is made worse by its dark color. Any combination of sunlight, heat, oxygen, and other factors may significantly increase its impact [20]. Researchers frequently utilize modifiers to make up for the inadequacies of the material because neat asphalt binder has poor distinctive quality. The adjustments and additions to the mixture could have an impact on the asphalt mixture. Modifiers are frequently used by scientists to improve the properties of asphalt binder and increase its efficiency.

2.5.3 Mineral Filler

When the aggregate passes through filter No. 200, it is clear that the asphalt mixture contains dust or mineral filler. The characteristics of Stone Mastic Asphalt (SMA) mixes are notably impacted by the choice of mineral fillers employed in their production. The matrix of the asphalt mortar is strengthened with mineral fillers. The incorporation of mental fillings could influence the operability, resistance to moisture, and aging characteristics of Hot Mix Asphalt (HMA) mixtures. To make asphalt last longer, mineral fillers are added; these additives also improve the mix's drainage issues and maintain the asphalt's original volume. Asphalt mixtures can contain a wide range of fillers, including conventional filler, quick lime, Portland cement, carbon black, hydrated lime, fine sand, and fly ash, according to [45]. Various filler types can be distinguished based on factors such as surface area, environmental particle volume, chemical properties, porosity, and other physical characteristics. Therefore, the type of filler employed will have an impact on how effective an asphalt mixture is [22]. The SEM images of several filler types are shown in Fig. 2.6.



a

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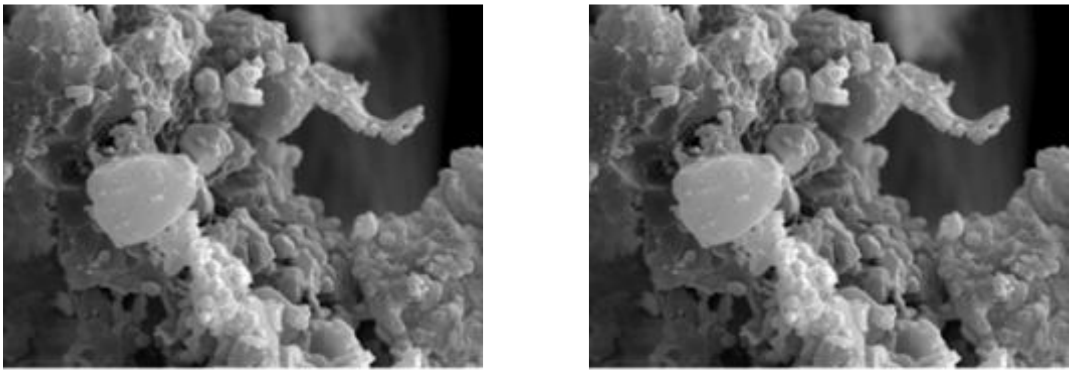
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Figure 2.6: Fillers.

Mineral fillers can be used for one of two purposes. First, it serves as a space filler and creates contact sites between aggregate particles as a structural component of aggregates. The larger aggregate particles are mixed with the asphalt binder, referred to as mastic in this instance, in a second role to improve adhesion. The effect that mastics have on the properties of the asphalt mixture has piqued the curiosity of asphalt makers, resulting in the creation of asphalt. The interactions between the filler and the asphalt, the filler's particle size, the temperature, and the loading period all have an impact on the tensile and shear strengths of mastic. If the dust/asphalt (D/A) factor is set at a value between 0.5 and 1.0, it may be easier to adjust the ratio of filler to asphalt binder. Researchers with the Strategic Highway Research Programmed (SHRP) developed this component. (0.6-1.2) [11]. (Rahman et al., 2020) Discovered that incorporating fly ash as a filler in Hot Mix Asphalt (HMA) mixes instead of using it as a second aggregate led to a 7.9% reduction in resilience modulus. Compared to the control sample, the final product exhibited a higher level of softness and a lower density. [28] investigated the impact of four different fillers (coal fly ash, utilizing ceramic waste, steel slag, and limestone as control materials)**.** Less than 1% of the dry weight of HMA is made up of HL. While some combinations may need lime concentrations as high as two and a half percent, some investigations have shown that a weight ratio of hydrated lime to aggregate of two percent is ideal [45]. When HL and asphalt mixes come into touch, a physicochemical reaction is considered to have occurred. In addition to lowering the ideal asphalt content by volume, this chemical can also be employed to physically fill in cracks in asphalt mixtures. The mixture's stability and resistance to fatigue cracking are both increased by the equal distribution of tiny particles throughout the mixture, which may result in fewer cracks showing up overall. It acts chemically as an active filler by reducing aging hardness and improving the mixture's resistance to moisture damage. This is because, when hydrated lime was used, it lessens ageing hardness [45] . American guillotine (AG) and Iranian guillotine (IG) were used to change bitumen, and the results created mixes that either met or exceeded the standards set by Superpave [44]. It is necessary to reach a TSR of at least 80%. The bitumen mixtures' resistance to degradation brought on by the action of water was aided by the inclusion of hydrated lime as both a filler and an additive.

The influence of incorporating hydrated lime as a filler in modifying mixtures, along with American and Iranian gilsonite (AG, IG), and styrene-butadiene-styrene (SBS) were all investigated by [44] for their effects on HMA performance. Figure 2.7 shows that every mix surpassed the 80% Superpave TSR criterion. The durability of the mixes to moisture-induced degradation was enhanced by the addition of bitumen modification additives and the use of hydrated lime as a filler.

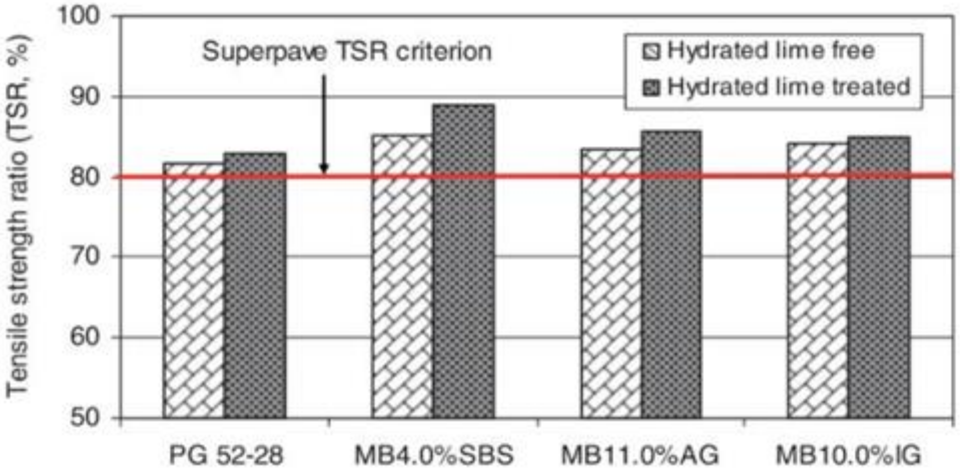


Figure 2.7: Tensile Strength Ratio Values for Mixtures.

2.6 APPLICATION FOR SMA

SMA has recently attracted considerable interest, particularly in the following applications:

a. Because SMA overlays can tolerate large traffic concentrations, they are used on autobahns (motorways) instead of dense-graded HMA.
b. Depending on the needs, SMA can be applied in thicknesses varying with width ranging from 2.6 to 5 times the particle size. Between these numbers, thickness may vary. It is economical to add tiny amounts of SMA to heavily graded HMA overcoats to restore skid resistance.

c. SMA can also be applied in circumstances where there are large load-bearing procedures.
d. The flexible SMA can also be used as the main layer of protection on bridge decks [38].

2.7 SUMMARY

A comprehensive understanding of the stone-matrix asphalt mixtures is provided by the review of the literature. The selection of Stone Mastic Asphalt (SMA) materials, their concentrations, and the associated test procedures were taken for the current study to underpin the main objectives of the investigation. While bituminous binders play a role in influencing the strength of the mix, the effectiveness of SMA mixtures is predominantly governed by the stone-on-stone contact within the coarse aggregate skeleton. Applications Cellulose is the main component of paper fibers, which is an example of an unusual fiber. Though it is widely and affordably available, especially in SMA blends, it is rarely addressed in the literature. As a result, it was suggested that this substance may be used to SMA blends as a stabilizing component. It would investigate the likelihood of using unconventional waste resources in an unconventional combination while also substantially reducing the problem of solid waste management.

3. METHODOLOGY

3.1. INTRODUCTION

This chapter delineates the experimental work conducted in the current investigation, categorized into two parts. The initial section encompasses testing on the components (aggregate gradation, bitumen grade, modifiers), while the subsequent section encompasses mixture tests essential for comprehending the behaviour of Stone Mastic Asphalt (SMA) both before and after modification.

3.2 TEST ON MATERIALS USED

The materials utilized in this study were made in Iraqi quarries, crushed limestone materials that were provided by *Karbala* quarry were employed to create SMA mixtures and their efficiency in enhancing road performance was examined.

3.2.1 Fine Aggregates

A local crusher provided the fine aggregates, which were stone crusher dust with fractions larger than 4.75 mm. They were then held on a 0.075 mm IS sieve. Table (3.1 shows the physical characteristics of the coarse and soft aggregate were evaluated in laboratory tests.

Table 3.1: Physical Characteristics of Fine and Coarse Aggregate.

Testing the properties of aggregate %	Specifications From ASTM	Results		Specification	
		Coarse	Fine	Coarse	Fine
Bulk SG of Fine Aggregate (g/cm³)	C12 (ASTM2015)	2.59			
The water absorption rate of the aggregate, %	C128(ASTM,2015)		2.61		
he waters absorption rate of the aggregate, %	C127(ASTM,2015)	2.25		5	
LOS angles abrasion, %	C128(ASTM2015)		2.41		
LOS Angeles abrasion, %	C131(ASTM2013)	26		30	
Percentage of fraction, %	D5821(ASTM2013)	100		100	
Percentage of fractured in two particles, %	D5821(ASTM2013)	95			90

3.2.2 Coarse Aggregates

Coarse aggregates consisted of the crushed limestone that was extracted from the Karbala quarry, up to 4.7512 mm size.

3.2.3 Filler

Filler is used in the creation the mixing of the asphalt since it has a number of advantages, including increasing life expectancy, increasing the resistance of the pavement to water damage, reduces the mixture's brittleness, bitumen viscosity, and bearing strength. On the other hand, the form chemical, and physical combination of the fillers, as well as their grade have a considerable influence on the effectiveness of the asphalt mixture; thus, the choice [24]. The filler is sometimes referred to as material finer than 0.075 mm for practical uses. This research employed two categories of fillers: Hydrated Lime (HL) and Ordinary Portland Cement (OPC). The Hydrated Lime (HL) was sourced from the Lime Plant of the Furat Company. Following the GSRB R9 specification, 1.5% of the overall aggregate weight in this study was derived from OPC and utilized as a filler. Table (3-2) and (3-3) show the chemical and physical properties of the fillers.

Table 3.2: The Filler’s of Chemical Structure.

Chemical Compositions	*Filler type*	
	HL	*OPC*
Al_2O_3	-----	2.325
Cao	90.586	65.147
MgO	3.602	1.327
SiO_2	0.891	25.41
K_2O	0.589	0.761
Fe_2O_3	2.254	1.125
Na_2O	1.002	1.714

Table 3.3: Physical Characteristics of Filler.

Property	*Filler type*	
	HL	*OPC*
Surface area density (m2 per kilogram)	*225*	345
Density (gm/cm^{3})	*2.62*	2.98

In addition, it in this study, another crucial impacting the properties of the asphalt mixing is the proper selection from the overall gradient. Table (3-4) and Fig. 3.1 show that The SMA mixture was designed using the middle gradation with a 19 mm Nominal Maximum Aggregate Size (NMAS). AASHTO M325 (AASHTO, 2012) provided recommendations for gradation limits.

Table 3.4: Gradation of SMA Mixture As Recommended.

Sieve (mm)	Size (in)	% Percent Passing	%of Passing/Selected Gradation
25	[1 in]	100	100
19	[3/4in]	90-100	95
12.5	[1/2in]	50-88	69
9.5	[3/8in]	25-60	42.5
4.75	[No.4]	20-28	24
2.36	[No.8]	16-24	20
0.075	[No.200]	8-11	9.5

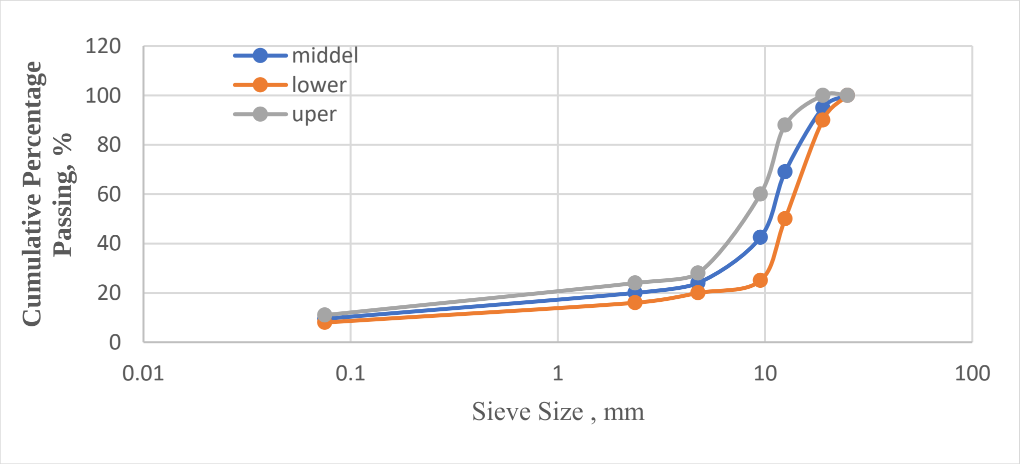


Figure 3.1: Suggested Defined Limits for Aggregate Gradation.

3.3 BINDERS (NEAT BITUMEN)

The used bitumen, which had a 40/50 penetration grade—the standard for thick-grade HMA used in Iraq—was supplied by the Al-Nasiriyah refinery in the country's south. As a control binder, it was recommended in this study to meet the requirements of the SMA mixture design.

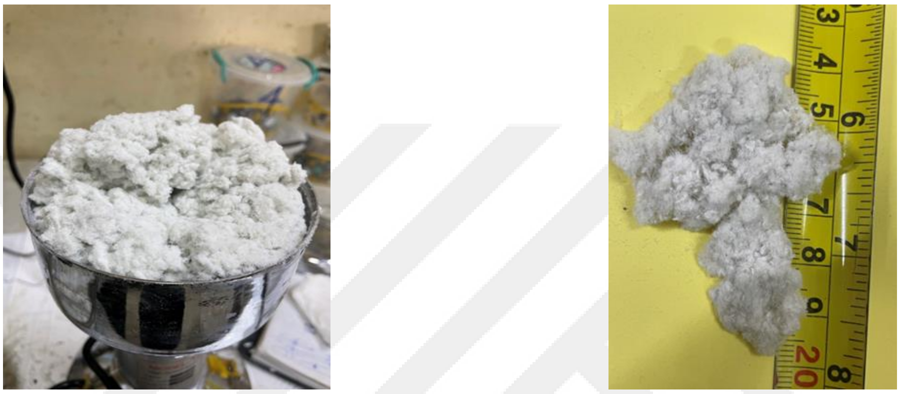
3.4 THE MATERIAL MODIFIERS

Improving the performance and increase the life of the SMA mixture, three different additive materials were added to the mixture by dry process, as shown in the next section:

3.4.1 Used Paper Fiber

Waste-Paper Fiber is a cellulose fiber variant derived from the recycling of locally generated waste papers. Consequently, the utilization of such materials can be viewed as a sustainable approach, contributing to the reduction of pollution concerns impacting the environment and public health. Since there is a high concentration of CaO and SiO2, the mastics stiffen more quickly, allowing the aggregate-binder link to be strengthened and the effective strength properties of the asphalt mixture to be improved. The chemical and physical characteristics of waste pape explained Table (3.6). In this research, paper was used after soaking and mixing it well with a hand blender until it turned into a material like threads, then drying it well and grinding it with a small mill to obtain fibers called paper pulp, as shown in Fig. 3.2.

a. Wet paper b. Paper after drying



c. After grinding d. Paper pulp

Figure 3.2: Paper Pulp.

Table 3.5: Chemical and Physical Characteristics of Waste Pape.

Chemical Analysis	
Chemical compositions	(%)
CaO	37.35
SiO2	5.011
MgO	0.696
Al2O3	3.431
P2O5	0.0443
SO3	0.1869
Cl	0.0420
K2O	0.0740
TiO2	0.126
MnO	0.0126
Fe2O3	0.3959
CuO	0.0181
ZnO	0.0339
SrO	0.0308
ZrO2	0.0165
LOI	52.52
Physical Properties	
Property	Obtained value
Surface area characteristics (m2 /kg)	1001
Porosity (%)	56

3.4.2 Cement Kiln Dust

Cement kiln dust (CKD) is a substantial waste product generated in large quantities during the production of Portland cement, as depicted in Fig. 3.3. Resembling Portland cement in appearance, A fine, powdery substance known as CKD is gathered from electrostatic precipitators during the cement clinker process. manufacturing process (Kunal et al., 2012). The primary constituents of CKD include lime, silica, alumina, and iron compounds. However, as a general guideline, the cementitious compounds in CKD are approximately one-third of those found in ordinary Portland cement [29,37]

CKD finds common applications in concrete mixes as a cement substitute, soil stabilization agent, in waste treatment, as filler material, or as a modifier in asphalt mixes. Incorporating Cement Kiln Dust (CKD) in asphalt mixtures can contribute to environmental goals by diminishing CKD deposits and mitigating the potential for air and water pollution [21]. This material has been employed either alone or in combination with other additives. In the context of this research, CKD is used as a modifier along with paper pulp and emulsion to enhance the properties of the Stone Matrix Asphalt (SMA) mixture. The chemical composition of CKD is detailed in Table (3-7).

Table 3.6: Properties and Chemical Composition of CKD.

Chemical Compositions	CKD
Al_2O_3	3.35
Cao	42.8
MgO	0.89
SiO_2	15.27
K_2O	1.05
Fe_2O_3	2.3
Na_2O	0.18
Loss on ignition LOI (%)	32.46
others	0.82

Figure 3.3: Cement Kiln Dust.

3.4.3 Emulsion

An emulsion is made up of three basic components: asphalt, water, and a small amount of an emulsifying agent. These elements are added to a colloid mill device during the same procedure, which the asphalt into small droplets by shearing. The surface-active emulsifier maintains the asphalt droplets in a steady suspension and regulates the breaking time. The material is a liquid product that may be utilized in cold operations for building and maintaining roads and has a viscosity that ranges from heavy cream to liquid. Nito proof 30 is a bitumen emulsion that was supplied from FOSROC company and used as binding agent. Table 3.8 shown in the properties of bitumen emulsion as supplied from the manufacturer.

Table 3.7: Emulsion Specifications.

Property	Value
Form	Dark brown liquid
Specific gravity	1.00
Solid's content	60 to 65%
Rubber content	Approx. 10 %
Drying time	30 minutes at 25°C
Over coating time	1 hour @ 25°C

3.4.4 Prepare the Additive for the Mixture

The dry approach was used to prepare the improved asphalt mixtures. That means adding the improved materials directly to the aggregate before adding the asphalt to the mixture. the improved material had to be made in a way that guarantees the spread of the material in the asphalt, Therefore, a mixture of the above-mentioned materials was produced in the proportions. The proportions are as follows: for every 50 g of emulsion, add 10 grammes each of paper pulp and Cement Kiln Dust, in addition to 5 grammes of thinner. The components were mixed in the form of small granules (EPC، as shown in Fig. 3.4 added with the aggregates in the room temperature to facilitate their spread in mixture rapidly and uniformly throughout the material and form a reinforcing network structure EPC was added to SMA components in different proportions, as shown in Table 3.10.

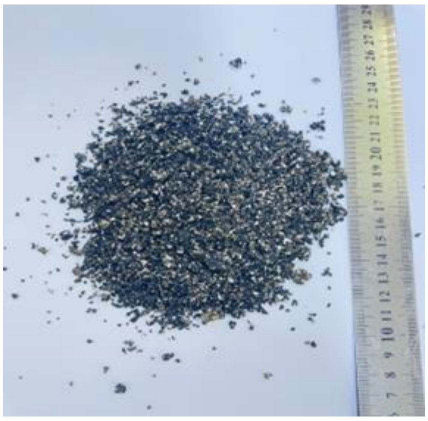


Figure 3.4: Materials for Additives (EPC).

Table 3.8: The Additives Ratio to Mixture Weight.

SMA Mixtures	Additives
SMA0	0 % EPC
SMA1	0.2% EPC
SMA2	0.4%EPC
SMA3	0.6%EPC
SMA4	0.8%EPC
SMA5	1%EPC

3.5 CREATING SMA MIXTURES

To find out how well they performed, five SMA asphalt mixtures were created, including the modified mixtures (MMs) and control mixture (CM). Two distinct types of specimens were utilized in the creation of these mixtures to fulfill testing requisites. The initial step involved preparing CM, with its four contents spanning from 6% to 7.5% in increments of 0.5%. This process aimed to adhere to the specifications outlined in AASHTO R46 for identifying the SMA-Control with the optimal Asphalt. The asphalt cement was heated to 165 degrees Celsius in order to reach the required rational viscosity of 170 plus 20 centistokes. Before the appropriate amount of asphalt cement was added, the aggregate was heated. As instructed in AASHTO T245 (AASHTO, 2004a), 50 blows of the Marshall hammer shown in Fig. 3.5 b on each face were used to create the Marshall samples with dimensions of 63.55 ± 2.55 mm (2.50 ± 0.20 in) in height and 100 mm (4 in) in diameter that are shown in Fig. 3.5 a. to reach the necessary air void threshold. Then, according to AASHTO M325 (AASHTO, 2012), SMA asphalt mixing, each with one of the four asphalt contents, underwent characterization through tests for tensile strength ratio, air voids and drain down. This process facilitated the identification of the mixture with the optimum asphalt content, labeled as the SMA-Control mixture throughout the study's duration. The subsequent phase involved the direct addition of the modifier to the aggregate sample in five different proportions: 0.2%, 0.4%, 0.6%, 0.8%, and 1% of the total SMA mix using the dry method.

In addition, other sample types prepared in this research were slab samples, requiring compliance with skid resistance and wheel track test specifications, with (300 x 165 x 40) mm.

a. Marshall specimen

b. Marshall Body

Figure 3.5: The Hammer.

3.6 METHODS FOR TESTING MIXTURES

A variety of testing procedures were used in order to evaluate the performance of stone mastic asphalt mixes by investigating the volumetric, mechanical, and durability. Table 3.10 includes a summary of the experimental testing methods utilized for determining these features.

Table 3.9: Test Program.

Property	Test Method	Standard	Importance of Tests
Volumetric Properties	VTM	ASTM D2041 (ASTM, 2015) ASTM D2726 (ASTM, 2011)	Offering indicators that aid in assessing the degree of compaction, aging, bleeding, and other relevant factors.
	V.M.A		
	V.F.B		
	Bulk Density		
Mechanical Properties	Marshall Stability and Flow	ASTM D6927 (ASTM, 2015)	Evaluating the resistance to plastic permanent deformation.
	Indirect Tensile Strength	AASHTO T283	Evaluating the potential of cracking.
	Skid Resistance test	ASTM E303 (ASTM, 2013)	Evaluating resistance to slipping
Durability Properties	Tensile Strength Ratio	AASHTO T283	evaluating resistance to water damage.

3.6.1 Ratio of Voids in Coarse Aggregate

The aggregate gradation's stone-on-stone contact function is measured using the voids in coarse aggregates (VCA) analysis. The SMA mixture was designed using this information. The AASHTO R46-08 (AASHTO, 2001b) Adhering to recommendations was essential to ensure optimal performance of the SMA mixture, particularly concerning stone-on-stone contact must be determined by determining which coarse pebbles actually contribute to this criterion, as demonstrated by Depending on the comparison that was made between the VCA obtained through the volumetric procedure and the DEM-IA procedure results, In certain cases, this sieve may have a size of 2.36 mm or 4.75 mm. For the aggregate gradation employed in this study, a 2.37-mm sieve was chosen. The VCADRC, VCAMIX, and PCA are determined using equations (3-1, 2, and 3) and the test protocol recommended in AASHTO T19M/T19-00 (AASHTO, 2004b). The bulk specific gravity of coarse aggregate was determined using AASHTO T85 (AASHTO, 2004c). However, in line with AASHTO T166 (AASHTO, 2005).

$$\mathrm{VCA_{DRC}} = \frac{\mathrm{G_{CA}}\gamma_{\mathrm{W}} - \gamma_{\mathrm{S}}}{\mathrm{G_{CA}}\gamma_{\mathrm{W}}} \times 100 \tag{3. 1}$$

$$\mathrm{VCA_{MIX}} = 100 - \left(\frac{\mathrm{G_{mb}}}{\mathrm{G_{CA}}} \times \mathrm{P_{CA}}\right) \tag{3. 2}$$

$$\mathrm{PCA} = \frac{\%\,\mathrm{R_{BS}}}{100} \times \left(1 - \frac{\%\,\mathrm{P_b}}{100}\right) \tag{3. 3}$$

Where:

GCA: Coarse Aggregate's Bulk Specific Gravity
γs: Bulk Density (kg/m³)
γw: Water Density, 998 Kg/m³ (62.3 lb/ft³)
PCA: Percentage of Coarse Aggregate in the overall mixture
Gmb: Bulk Specific %
RBS: Aggregate Retained %
Pb: Percentage of Asphalt in relation to the total mixture weight

3.6.1.1 Evaluation of drain down test

When designing Stone Matrix Asphalt (SMA) mixtures, the drain down test is an essential assessment because SMA mixtures have higher asphalt and filler contents than dense graded mixtures. SMA is more prone to drainage problems as a result of its higher content, particularly when mixing, storing, and compacting (Devulapalli et al., 2020). The maximum allowable level of drain down is 0.3%, according to AASHTO M325-08 (AASHTO, 2012). According to the recommendation of AASHTO T305-03 (AASHTO, 2001). In this test, four samples are utilized, with two of them tested at the predictable plant production temperature and the remaining two at the expected plant production temperature plus 15 degrees. The test entails using a loose the mixing deposited in a standard basket with a 6.3 mm mesh, situated over a known weight pan. (refer to Fig. 3.6). Subsequently, the drain down sample undergoes conditioning in a force draft oven for one hour, plus or minus five minutes, as depicted in Fig. 3.7, in accordance with the guidelines outlined in AASHTO T305

(AASHTO, 2001a). Subsequent to the conditioning phase, the pan and the sample-filled basket are extracted from the oven and allowed to reach room temperature. Equation (3.4) is employed to calculate the drain down amount.

$$\text{Draindown (percent)} = \frac{D - C}{B - A} \times 100 \tag{3.4}$$

where:

A: mass of the empty basket,

B: mass of the basket and sample,

C: mass of the empty catch plate, and

D: mass of point C above plus drained material.

Figure 3.6: Configuration of the Basket and Sample for the Drain Down Test.

Figure 3.7: Utilization of a Forced Draft Oven.

3.7 EXAMINATION OF MECHANICAL CHARACTERISTICS

The correlation between load (stress) and displacement (strain) defines the mechanical properties of a material. Fundamental material qualities are derived from essential units and remain free of testing dimensions or specimen shape. To evaluate the mechanical characteristics of Stone Mastic Asphalt (SMA), numerous tests were conducted. The following sections provide a brief overview of various tests.

3.7.1 Stability and Flow Testing in Marshall Asphalt Testing

According to ASTM D6927 (ASTM, 2015a), specimens are prepared and undergo testing to ascertain Marshall Stability (MS) and Marshall Flow. This technique is employed to assess the mixture's resistance to plastic deformation.

3.7.1.1 The Test of indirect tensile strength

The test lies in its ability to determine the tensile strength of asphalt mixtures, which is directly related to cracking problems. Three sets of samples are used in the test process, as described in AASHTO T283. Then the mixture is baked for two more hours at the mixing temperature in an oven. The samples are subsequently compressed with a Marshall Hammer. Three samples were prepared for testing under dry conditions at 25°C. Fig. 3.8 illustrates the ITS test device. The equation that has been used to obtain the Indirect Tensile Strength as stated AASHTO T283 (AASHTO, 2003b).

$$\mathrm{ITS} = \frac{2000\mathrm{P}}{\mathrm{D.t.\pi}} \tag{3.5}$$

Where:

IDT=Indirect tensile strength, kPa
P=maximum load, N
t=specimen height immediately before test, mm
D=specimen diameter, mm

Figure 3.8: Instrument for Indirect Tensile Strength Testing (2003b).

3.7.2 The Resistance Skid

The skid resistance has been considered an important factor that controls the amount of tire contact with pavement and has a significant impact on the traffic safety of pavements. British Pendulum Tester (BPT 3-9) was used to determine the slip resistance of SMA asphalt mixtures in terms of the British Pendulum Number in accordance with ASTM E303 (ASTM, 2013b) (BPN). To conduct this test, wheel track slab samples measuring 300×165×40mm were employed. The asphalt mixes underwent testing under both dry and wet conditions to assess their frictional properties. Four readings were taken for each specimen and under each condition, and the average of these readings, indicative of the skid resistance of the tested object, was determined. Figures 3.9 and 3.10 depict the device and the sample.

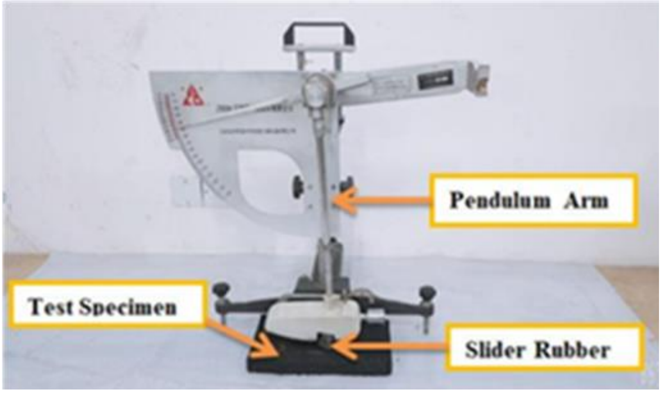


Figure 3.9: The British Pendulum Device.

Figure 3.10: Slab Sample of Skid Resistance.

3.7.3 Examination of Durability Characteristics

Durability refers to a substance or structure's capacity to withstand repeated stresses over time without deteriorating noticeably. The effects of aging and moisture damage are greatest on asphalt pavement materials. As the asphalt cement hardens, the mixture stiffens and the material properties change. Next parts focus on the setup and conditions of the durability tests.

3.7.4 Indirect Tensile Strength Ratio TSR

One of the primary types of distress that leads to the start and escalation of According to [42], moisture damage is one of the other forms of distress. The resistance of the asphalt mix to stripping can be determined using this modified method, depending on the test (Lottman, 1982) and (AASHTO T-283) (AASHTO, 2003b). The criterion used to evaluate moisture damage resistance in samples is the indirect tensile strength ratio (TSR), calculated by comparing the Indirect Tensile Strength (ITS) of conditioned samples to the ITS of dry samples. The ratio defines how susceptible an object is to moisture damage. The conditioning stage includes curing it at 60 °C for 16±1 hours before being compacted. Then, the procedure of this test consists of freezing for 18 hours at -18 °C and then thawing in water for 24 hours at 60 °C, the strength of the samples will lessin. The specimens were put in a container and covered with a plastic bag, with the top surface cut away so that water could enter the specimen during conditioning. In order to keep the specimens from drying out during conditioning, this was done. The strength of a mixture decreases less dramatically during conditioning if it has a greater stripping resistance to begin with. need Six samples—three dry and three wets are needed to get an accurate TSR reading.

$$\text{TSR} = \frac{\text{ITS conditioned}}{\text{ITS uncconditioned}} \tag{3.10}$$

3.8 METHODOLOGY

To accomplish the major objective of this thesis, an analysis of types Stone Mastic Asphalt (SMA) mixtures was conducted, focusing on their volumetric and mechanical properties. Additionally, a literature review was undertaken to explore the development concepts in SMA.

a. Prepare the SMA0 mixture or control to test its volumetric and mechanical properties.
b. Incorporating environmentally friendly modifiers into the asphalt binder, including 0% EPC, 0.2% EPC, 0.4% EPC, 0.6% EPC, 0.8% EPC, and 1% EPC at various proportions to achieve SMA0, SMA1, SMA2, SMA3, SMA4, SMA5.. This step includes testing changed asphalt characteristics and modified concentrations.
c. This study evaluates variable volume, mechanical, and durability asphalt mixes using a predetermined additive.

4. THE RESULTS AND DISCUSSION

4.1 GENERAL

This chapter reveals the outcomes associated with the study materials and interprets the data obtained from practical tests using a procedure that involves modifying the properties of the mixture through the addition of enhanced materials using the dry method for the development of Stone Mastic Asphalt.

4.2 EXAMINATION OF STANDARD STONE MASTIC ASPHALT

SMA 0, virgin coarse and fine particles, a penetration grade of 40–50, and two types of fillers—ordinary Portland cement (OPC) and HL—were used to create the control mixture of Stone Matrix Asphalt (SMA). The Nominal Maximum Aggregate Size (NMAS) of the aggregate gradation that was used was 19 mm. Four asphalt contents—6%, 6.5%, 7%, and 7.5%—were used to determine the ideal unmodified SMA mixtures. These contents were chosen in compliance with AASHTO R46 and the recommendations given in (AASHTO, 2001b). In accordance with AASHTO M325 (AASHTO, 2012) recommendations, the air void content, the investigation assessed voids in mineral aggregates, drain down of Stone Mastic Asphalt (SMA) mixtures. The mixture designated as the control mixture (CM) featured Ordinary Portland Cement (OAC). The detailed results are provided in the subsequent sections.

4.3 ASSESSMENT OF VOLUMETRIC CHARACTERISTICS FOR STANDARD STONE MASTIC ASPHALT (SMA).

The structure of the SMA mixture mainly depends on the volumetric properties of the mixture. Four different percentages of AC were used in the basic SMA formulations, which were created in standard (coarse, medium, and fine) gradations (i.e., 6, 6.5, 7, and 7.5%). Subsequently, the optimal gradation was selected based on criteria such as air voids, voids in the aggregates, and voids in coarse aggregates. Finally, a series of experimental results shown below show how to use ideal gradation with a predetermined AC current to fabricate the SMA mixture assemblies required for OAC calculation.

4.3.1 Characterization Density of Control SMA (BD)

Fig. 4.1 depicts the bulk density of compacted Stone Mastic Asphalt (SMA) mixtures transitioning in response to changes in the amount of AC in the mixture. Density decreases slightly when the AC rises to a certain value, corresponding to 6.5%. This is a possible behavior that may occur as a result of increasing the asphalt content, and at this point, the density of mixing begins to decrease, so increase in the lower-density binder compared to the aggregate. That is, it can be attributed to the fact that the mixture contains an excessive amount of asphalt, which causes the mixture to behave in an unpredictable manner, which ultimately leads to an increase in volume as well as an increase in the amount of loss that occurs during the mixing process, these results were also confirmed by MS2. This behavior is plausible because of the increase in the asphalt content provides the mixing with much lubrication, simplifying the sample compression procedure. Consequently, air voids decrease as the asphalt fills the voids, and the asphalt mixture densifies. This, in turn, leads to a reduction in the volume of the mixture and an increase in its weight. Which leads to an increase in density.

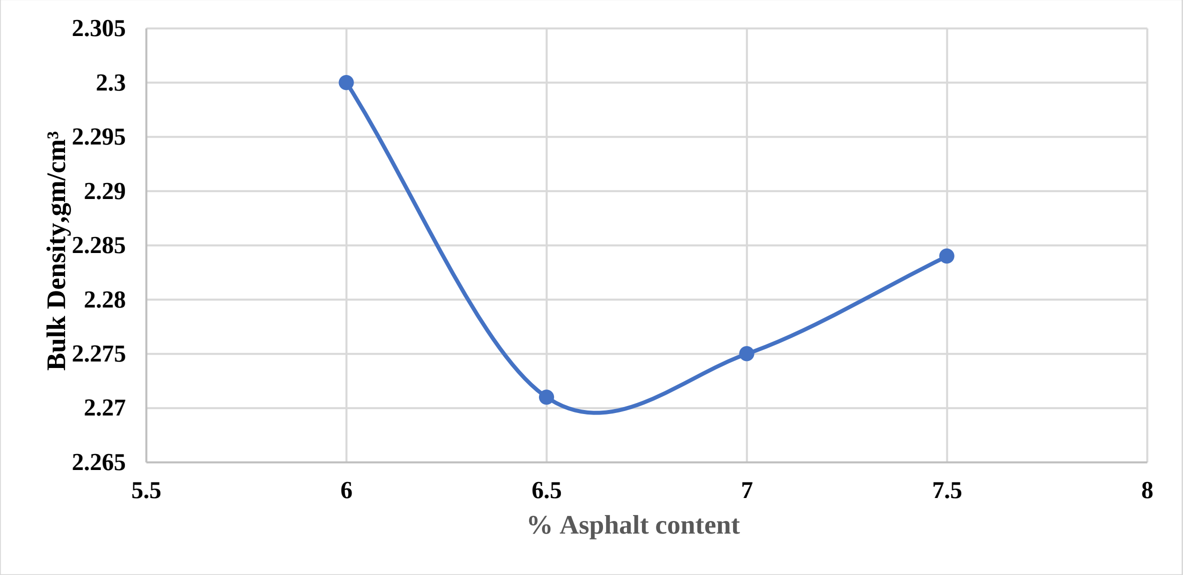


Figure 4.1: Bulk Density gm/cm³ of the Control Mixture.

4.3.2 Determination of The VCA Of the Control Mixture

Table 4.1 illustrates the volumetric properties of SMA with various asphalt binder contents. However, with the mix design key property of SMA, VCAMIX/VCADRC should be less than. The results below showed that it is within the range of asphalt binder of 6-7.5%, so al asphalt SMA types meet this requirement. That is, there is a stone-on-stone contact offered by all SMA controls, and semiannually, there is sufficient area of aggregate to accommodate the asphalt binder, which subsequently reflects the mechanical properties of the SMA within the specified asphalt binder range where the coarse aggregate skeleton can transfer the traffic load.

Table 4.1: Holes in Coarse Aggregate Data.

AC, %	G_{CA}	P_{CA}	***BD***	***AV***	VCA_{DRC}	VCA_{MIX}	VCA_{MIX}/ VCA_{DRC}
6	2.6	75.2	2.3	4.5	38.1	34.47	0.90
6.5	2.6	74.8	2.271	4.4	38.1	34.98	0.918
7	2.6	74.4	2.275	3.5	38.1	35.75	0.912
7.5	2.6	74.0	2.284	3.08	38.1	35.39	0.928

4.3.3 Air Void of Control SMA Mixtures

Air voids play a crucial role in influencing asphalt properties throughout the life service, and the centenary of air voids within the mixing is a key factor. In Fig. 4.2, the behavior of the air void content in the unmodified SMA asphalt mixture is depicted for the specified asphalt contents, following the recommendations of ASTMD7064/D7064M (ASTM, 2013c). It is required that the percentage of air voids in SMA asphalt mixtures should be 4 percent. As shown in Fig. 4.3, the results indicate a decrease in the percentage of air voids with an increase in the asphalt content (AC) value, reaching 3.08% at 7.5% AC. This suggests that the asphalt binder fills the gaps between the aggregates, resulting in a reduction of air voids. The results align with observations made by [34].

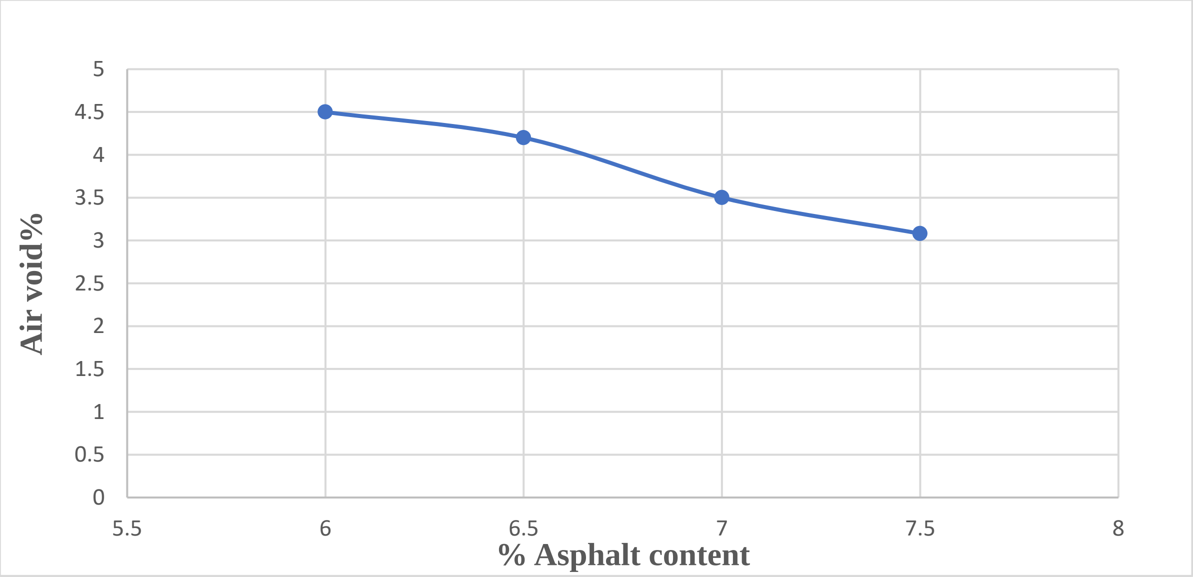


Figure 4.2: Air void% of Control Mixtures.

4.3.4 VMA of Control Mixtures

The volume of intergranular void space between aggregate particles in a compacted paving mixture, including air and active voids, is referred to as voids in mineral aggregates (VMA). VMA plays a crucial role in influencing the durability of the asphalt mixture. A low VMA suggests the presence of a thin layer of asphalt covering the aggregate particles, indicating reduced durability, and vice versa [2], In Fig. 4.3, the results of the VMA analysis for the unmodified SMA asphalt mixture are presented. The findings show variations in VMA values with changes in AC. This indicates that an increase in AC leads to a thicker asphalt coating layer and, consequently, an increase in VMA. Similar observations were reported by [34]. However, all asphalt binder contents within the SMA mix design requirements exceed 17% VMA, meeting the specified requirement.

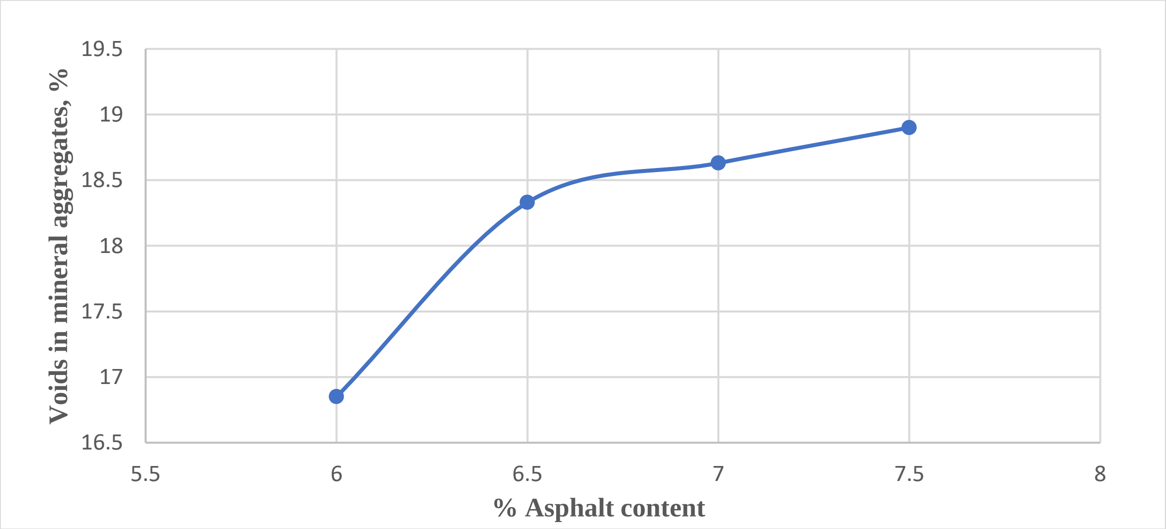


Figure 4.3: Void Content in Mineral Aggregates of the Standard Mixture.

4.3.5 Void-Filled Asphalt Control Mixture

Providing an indication of mixture durability. In Fig. 4.4, it is observed that VFA gradually increases with a rise in asphalt content, reaching 87.28% when the asphalt content is 7.5%. This increase is attributed to more asphalt filling the spaces previously occupied by air. The results demonstrate that the volume fraction of asphalt (VFA) increases with an increase in the amount of asphalt binder.

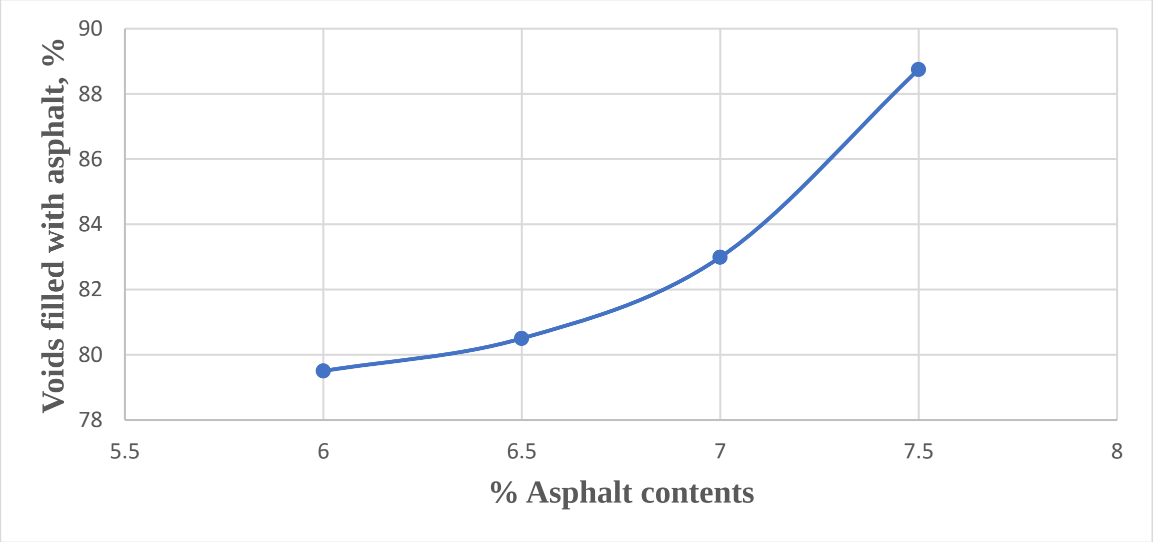


Figure 4.4: Asphalt-Filled Voids in the Standard Stone Mastic Asphalt (SMA) Mixture.

4.3.6 Drain Down Attributes of Control SMA Mixtures

Because of the increased levels of asphalt binder and filler integrated into the formulation of the Stone Mastic Asphalt (SMA) mixture, it is susceptible to the adverse effects of segregation during various stages, particularly in the design phase, compaction process, and under high operating temperatures. It is imperative to note that the percentage of drain down in SMA asphalt mixing do not surpass 0.3%, as specified by [13]. Results of a drain test performed across two correlated temperatures. It is very evident that the levels of drain down seem to be more than specified by requirement at both temperatures (anticipated and anticipated +15). This is the case for the entire AC range. Fig. 4.5 shows results of drain down. When 7.5% AC is used, the excess amounts of increment reach 2.25 and 3.4%, respectively, at 165 and 180°C. It is possible that this is because the SMA mixture has a higher percentage of asphalt and a coarser aggregate gradation. In addition, since pure bitumen has a lower viscosity than other modified bitumen types, a portion of the asphalt containing a small amount of filler material is separated from the mixture.

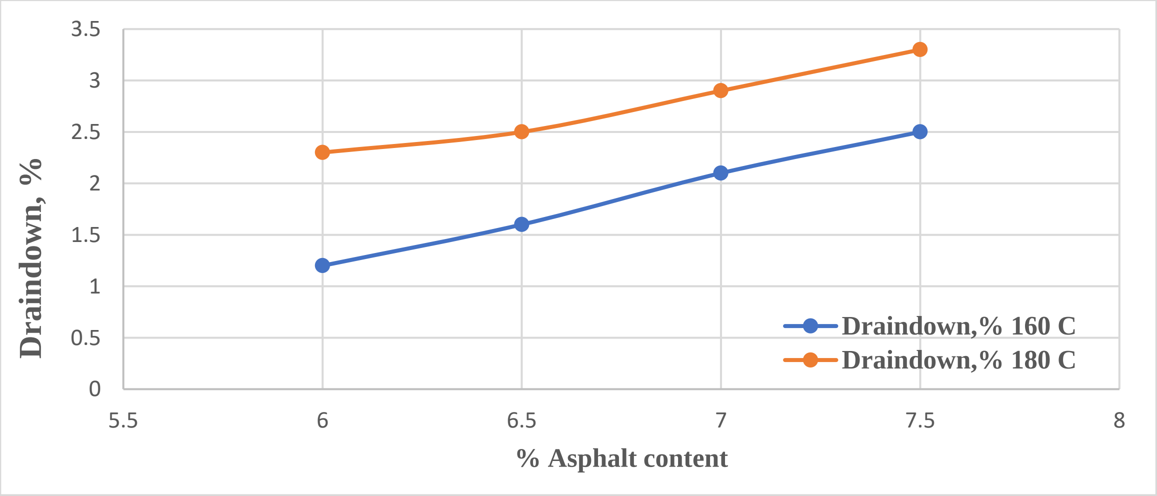


Figure 4.5: Drain Down of Control SMA.

4.3.7 Drain Characteristics of OAC With SMA Mixing

The outcomes indicate 6.65% of the asphalt meets the optimal criteria for drain down, air voids tests, along with VMA and VFA properties. The SMA mixture will be utilized alongside the OAC mixture as the control mixture (CM for the optimization process. Conversely, the result shows that there is a need for development because the neat binder alone is not able to offer the required properties of the SMA mixture, especially with regard to the drainage. This is the case because a neat binder alone cannot provide the required properties of the SMA mixture. Therefore, the next section will explain how to implement the proposed change and what the results of this change will be.

4.4 ATTRIBUTES OF MODIFIED STONE MASTIC ASPHALT MIXTURES

With the great growth of industries, various problems have arisen. And more and more appeared, including the rapid degradation of natural resources and severe environmental pollution. Daily accumulation Waste is one of the causes of these problems, especially paper and cement kiln dust produced from cement factory waste. In this study, a unique process for the dry preparation of stone asphalt (SMA) was proposed and tested in this study, the tests, which consisted of five different combinations: complete volumetric, drain down, indirect tensile strength, and Marshall stability tests; the Marshall flow test; the TSR test; the skid resistance test; and the wheel track test, were compared to those of the control SMA mixture, and the results of these tests were analyzed and compared.

4.4.1 Density of Modified SMA

Figure 4.6 illustrates the bulk density of SMA mixing with varying proportions of additives. The SMA modification uses small granules from EPC additives that are produced from paper pulp with CKD and other activated additives, added in a dry process method. However, the addition of these granules introduces a moderate variation in density. The findings suggest that the incorporation of paper pulp (PP) and cement kiln dust (CKD) with Stone Mastic Asphalt (SMA) mixtures increases the density of these mixing up to a certain dosage. The addition of paper pulp (PP) and CKD (EPC) resulted in a density higher than that of the control mixture. The SMA mixture containing 0.6% EPC exhibited the highest bulk specific gravity values at 2.336. This could be stemming from the increased viscosity of the asphalt binder to ensure 100% aggregate coating. Where the mixture containing 1% EPC 2.32 had the lowest values, the density decreased when the added material was increased, down to 1%, which is equal to 2.32. This decrease is due to the higher viscosity resulting from the mixing of these percentages with asphalt, as mentioned earlier. The high amount of EPC negatively affects the SMA mixture. [35] indicated that fillers with high porosity and surface area can absorb an additional amount of asphalt binder.

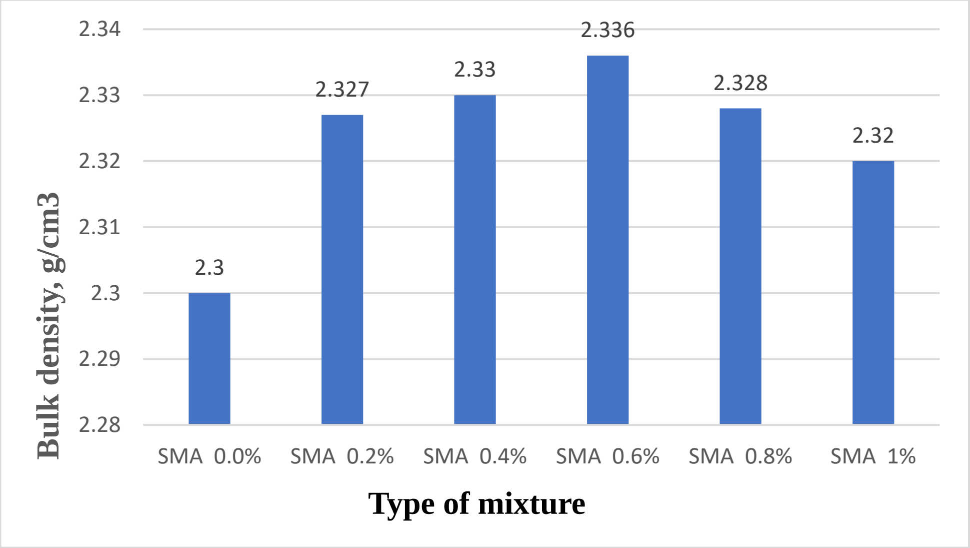


Figure 4.6: BD of Control and SMA Mixtures.

4.4.2 AV of Modified SMA

Fig. 4.7 displays the percent air voids in SMA mixtures with the EPC additive. The data showed a positive correlation between AV and EPC. The measured AV values from EPC contents were between 3.32% and 4.5. The density of paper pulp fiber and Cement Kiln Dust (CKD) is considerably lower than that of aggregates, facilitating their penetration into the aggregates and resulting in the formation of a proper coating over them. The filling properties provided by these additives contribute to a reduction in air voids in the stabilized mixture compared to the control mixture. This reduction is attributed to more compact between the asphalt-modified binder and aggregate and reducing the number of air pockets. Then, increasing EPC content by adding 0.8% to 4.2 and 1% to 4.5, due to the effect of EPC on the mixture and its high viscosity, makes the mixture resistant to compaction , shows a similar result by [35].

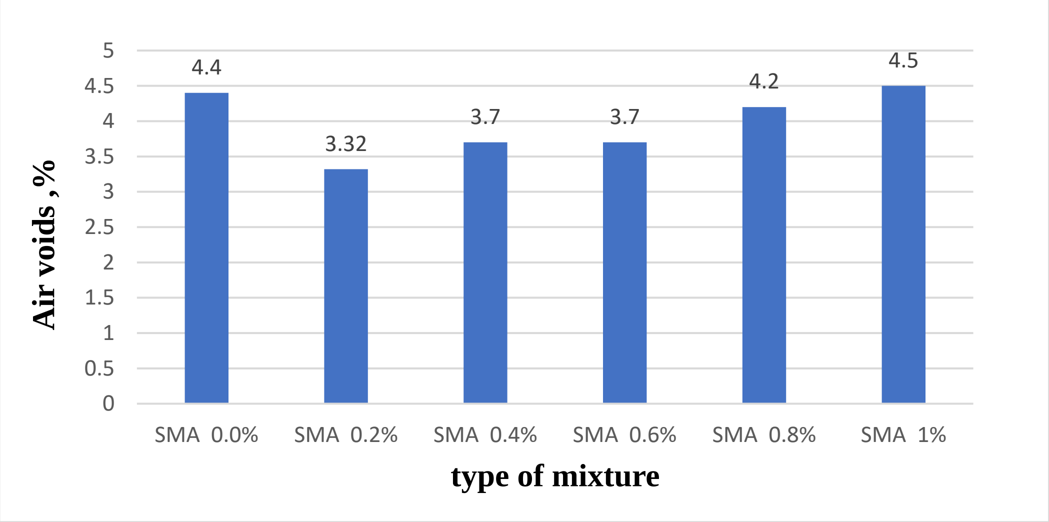


Figure 4.7: Air Voids in Control and SMA Mixing.

4.4.3 Mineral Aggregate

Fig. 4.8 displays how the trend of the VMA values of the SMA mixture with and without modifier mixture is similar to the trend of the air void results. Results show that the use of waste additive materials has an influence on the amount of VMA. The VMA result pattern for the SMA mixture modified with paper pulp and CKD has lower VMA values compared to the control mixture. Also, the amount of EPC added increases, leading to a decrease in VMA. except for the mixture of 0.8% and 1% EPC, where the addition led to an increase of 5.7% and 4%, respectively, contrasted to the control mixture. It indicates that the viscosity qualities, along with the surface area of the filler ingredients, play a role in regulating the volumetric properties of SMA mixes.

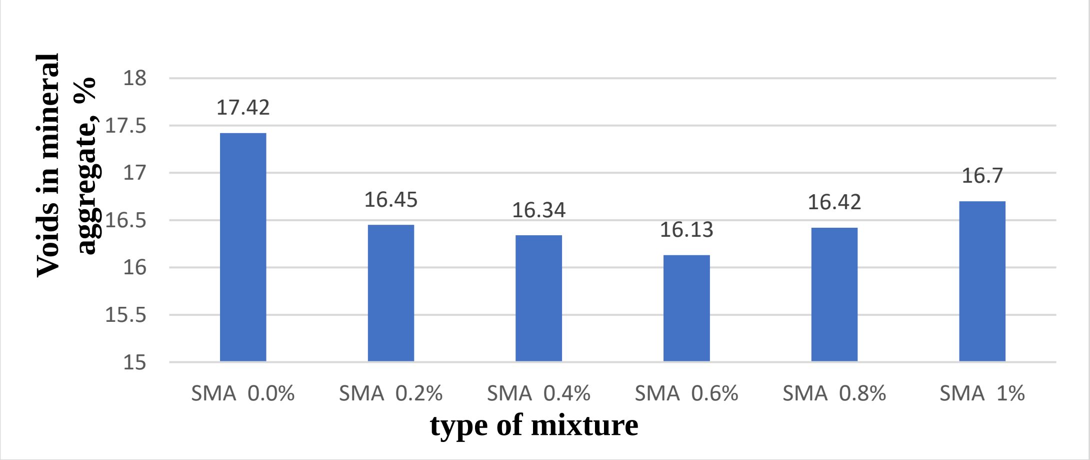


Figure 4.8: VMA of Control and Modified SMA Mixtures.

4.4.4 VFA of Modified SMA

Fig. 4.9 summarizes the percentage of voids in mineral aggregate (VFA) that are filled with asphalt in SMA mixtures with different ratios of additions that have an influence on the amount of VFA. where the VFA showed a positive effect and an increment compared to the SMA0 mixture. Also, results show that VFA increases as additive content increases; the amounts increase by 7.1%, 8%, 9.7%, 7.4%, and 5% at the dosages of 0.2%, 0.4%, 0.6%, 0.8%, and 1% of the additives, respectively. An important conclusion may be drawn from these results. When the paper pulp and CKD are added to the mix, these modifiers exhibit network properties that function to obstruct additional air voids, which then leads to risen in VFA, decreasing the number of voids of the air.

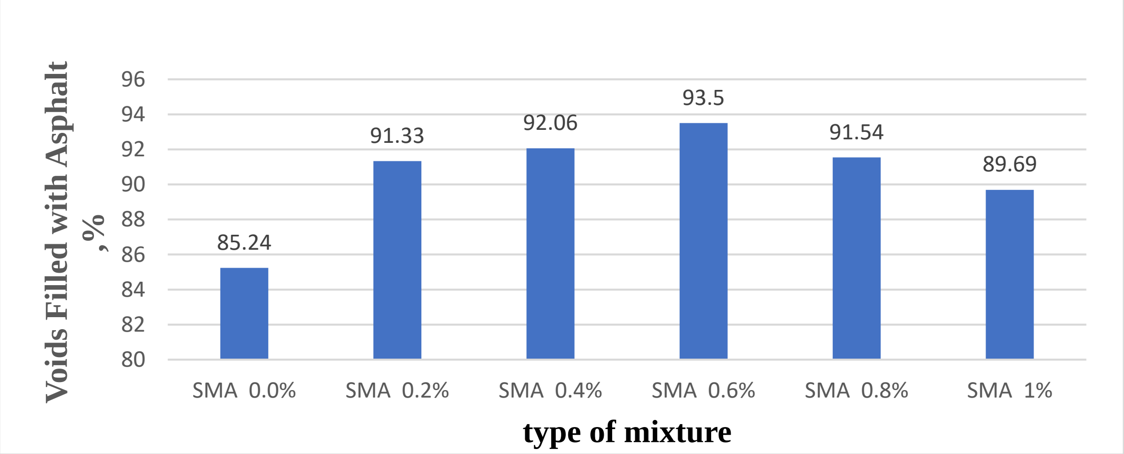


Figure 4.9: Holes Filled with Asphalt in Control and SMA.

4.4.5 Drain Down

The results of the drain down test for each mixture type, after an hour of drying in a forced-oven, are illustrated in the figures. This test provides an indication of the efficacy of modification materials in preventing binder runoff. Results It indicates that the use of additives helps decrease the drain down amount, which is lower than the control mixture at different levels. Fig. 4.10 and plate (4-1) The results demonstrate that the incorporation of EPC in the modification of the Stone Mastic Asphalt (SMA) mixture aids in reducing the drain down amount below the minimum level, which reached 0.01% at 160°C and 0.02% at 180°C, respectively, at 1% EPC. This is because of the high viscosity values of the asphalt binder, which contains SiO2 and CaO compounds along with paper pulp that has been treated with CKD. This, by acting as a reinforcing material and promoting adhesion bonding between asphalt binder and aggregates due to fibers' absorptive nature, greatly improved performance and reduced drain down. This demonstrates that every addition functions as a stabilizing component in all mixtures, adhering to a comparable outcome of SMA modified with C25 fiber [26].

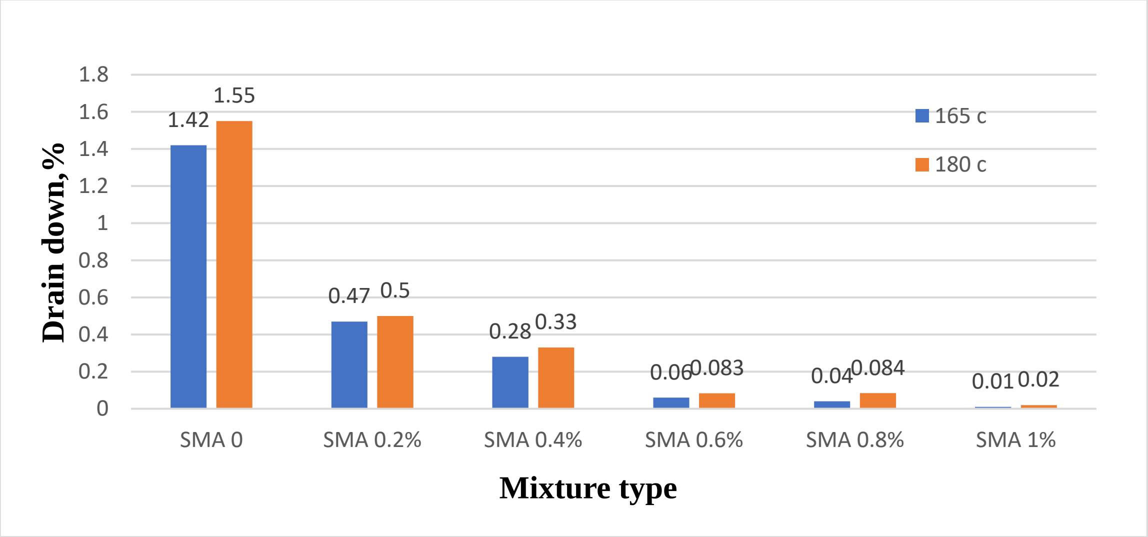


Figure 4.10: Drain Down in Control and Modified SMA Mixtures.

4.5 MECHANICAL TEST RESULTS OF MODIFIED SMA:

4.5.1 Stability and Flow Characteristics in Marshall Asphalt Testing

Marshall stability is a measure of how susceptible it is to deformation due to the constant and intense stress of traffic at an elevated temperature. In general, Fig. 4.11 shows that the result of Marshall stability when additives were added as 0.2%, 0.4%, 0.6%, and 0.8% of the weight of the mixture has increased by about 14, 13, 15, and 17%, respectively. By thickening the asphalt film covering the aggregates, these additives improve the mixture's stability. This outcome is very similar to the explanation provided by [26]. The trend of improvement appears to have stopped after the amount of EPC was increased to 1%; this could be due to the additive's porous nature, which increases the amount of asphalt binder absorbed and, in turn, thickens the asphalt binder film.

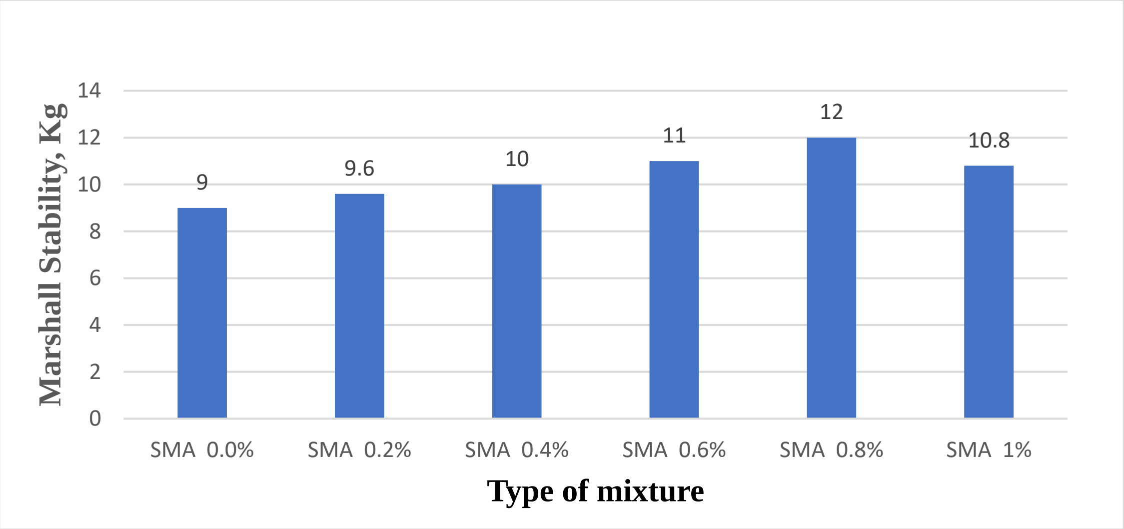


Figure 4.11: MS of Control and Modified SMA Mixtures.

Fig. 4.12 flow values showed a noticeable decrease with the increase in PP with CKD additives; this is due to the hardness of the mixtures. In comparison to the SMA0 combination, the values of flow in SMA0.2%, SMA0.4% and SMA0.6 have decreased by about 14, 13, 15, and 17%, respectively. Afterward, Marshall Flow (MF) started to increase again with the elevation of EPC additive to 0.8% and 1%, in comparison to the SMA0 mixture. These findings are consistent with the observations made by [26]. The amalgamation of the materials, PP and CKD, and their incorporation in specific proportions may diminish the flowability of mixtures under loading.

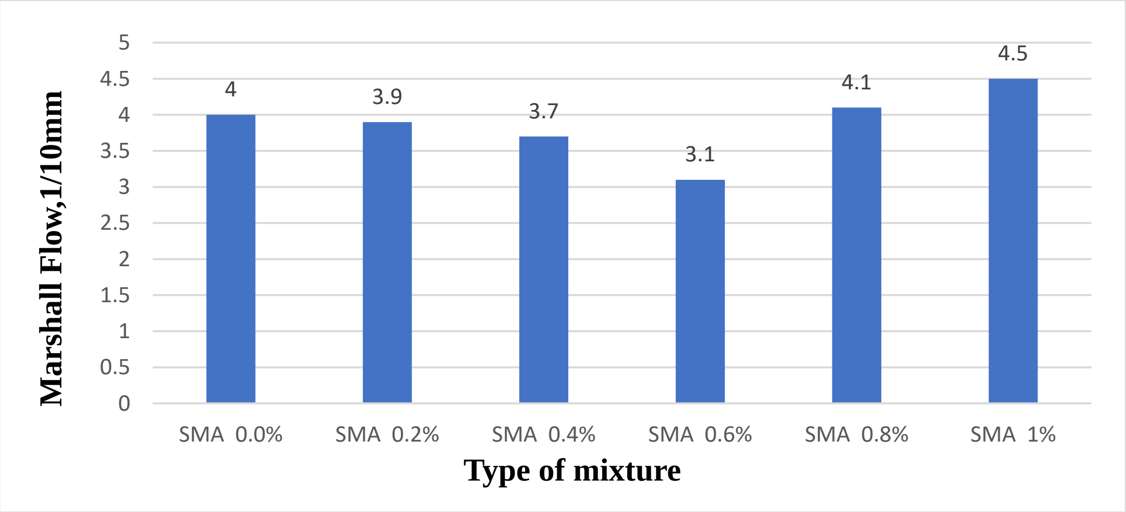


Figure 4.12: FM of SMA and Control Mixtures.

4.5.2 Evaluation of The Indirect Tensile Strength

The results of ITS are summarized in Fig.4.13, and this the results also show that the use of PP and CKD together leads to an increase in ITS increases steadily as pp and CKD content increases compared with SMA0 mixture, and it achieves an increment of 37% at 0.8% EPC (pp and CKD). This means that additives have a positive effect. The reason is attributed to Paper pulp is characterized by its porous nature, in addition to the presence of CaO and SiO2, which give asphalt rigidity properties. Also, due to the presence of SiO2 in CKD, when increasing the dosage of PP and CKD together, this increases the asphaltene adhesive part when adding this material to asphalt due to the polar nature of this material. That can make the mixture stiff and increase the reinforcement of bitumen by tiny additive particles, therefore increasing the mixture's resistance to cracks. Then the ITS has begun to decrease in SMA1% but remains higher than the Control mixture SMA.

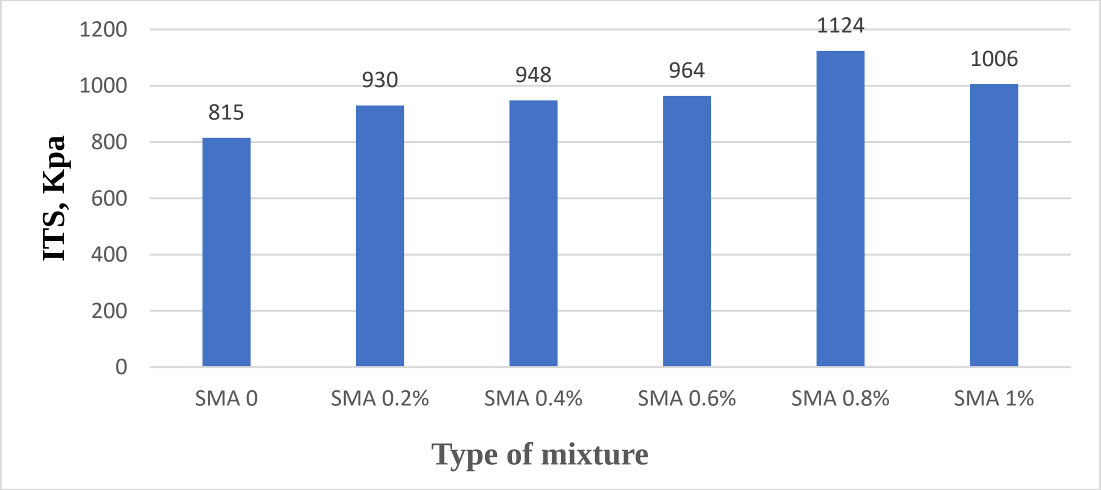


Figure 4.13: ITS of Control and Modified SMA Mixtures.

4.5.3 Skid Resistance Test

The outstanding traction of Stone Mastic Asphalt (SMA) mixed surfaces is advantageous in both dry and wet conditions. The skid resistance of the mixed surface noticeably increased in all modified SMA mixtures containing SMA0.2, SMA0.4, SMA0.6, SMA0.8, and SMA1% by around 40%, 22%, 13%, 31%, and 35%, respectively, in the dry condition. Under wet conditions, the resistance of the mixed surface to the skid is increased by approximately 26%, 38%, 21%, 22 %, and 17%, respectively. This suggests a stiffening of the asphalt binder, preventing the aggregate from sliding under the weight of moving traffic, as well as an improvement in the macro-volumetric properties of the SMA surface texture. Modifier application also strengthens the characteristics of surface roughness by enhancing the pavement's micro-texture qualities. Increasing the tire’s contact surface area with the pavement is another way to increase friction forces. Findings in Fig. 4.14 show that the skid was higher when the SMA0 combination was mixed but lower when it was wet.

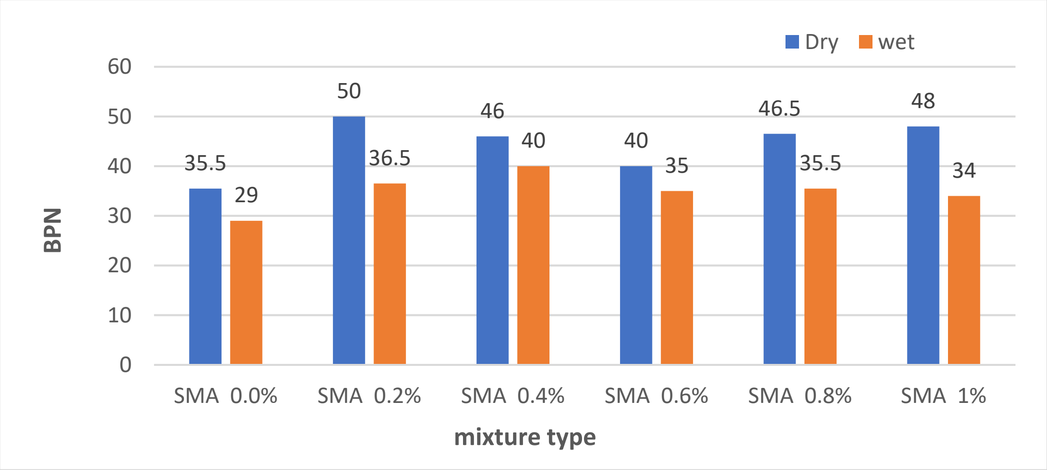


Figure 4.14: Traction Performance in Control and Modified Stone Mastic Asphalt (SMA) Mixtures.

4.5.4 Durability Tensile Strength Ratio (TSR)

The Tensile Strength Ratio (TSR) of Stone Mastic Asphalt (SMA) mixtures is defined as the ratio of wet to dry Indirect Tensile Strength (ITS). Typically, unconditioned specimens (dry ITS) exhibit higher values than conditioned (wet ITS) specimens. The decrease in ITS for conditioned samples can be attributed to the loss of adhesion between the asphalt binder and aggregate or the loss of cohesion in the asphalt binder due to prolonged exposure to water. The results of TSR for the control and EPC-modified SMA mixtures are depicted in Fig. 4.15. The testing results indicate that the ITS for modified SMA mixtures with varying percentages of EPC has a significant impact on the TSR of the mixtures. The addition of 0.2% EPC increases the TSR, attributed to the enhanced stiffness of the asphalt binder resulting from the influence of SiO2 molecules. These molecules work to increase cohesion between bitumen molecules and enhance the polarity of asphalt, as noted by [25,39].

As the content of EPC continues to increase, the TSR begins to increase with additions of 0.4%, 0.6%, and 1% EPC of the weight of the mixture, but not to a level less than the TSR of the control mixture. All the EPC mixtures exhibited superior resistance to moisture damage compared to the other compound mixtures, except for the 0.8% mixture, which falls outside the specified limit range of 70–90%.

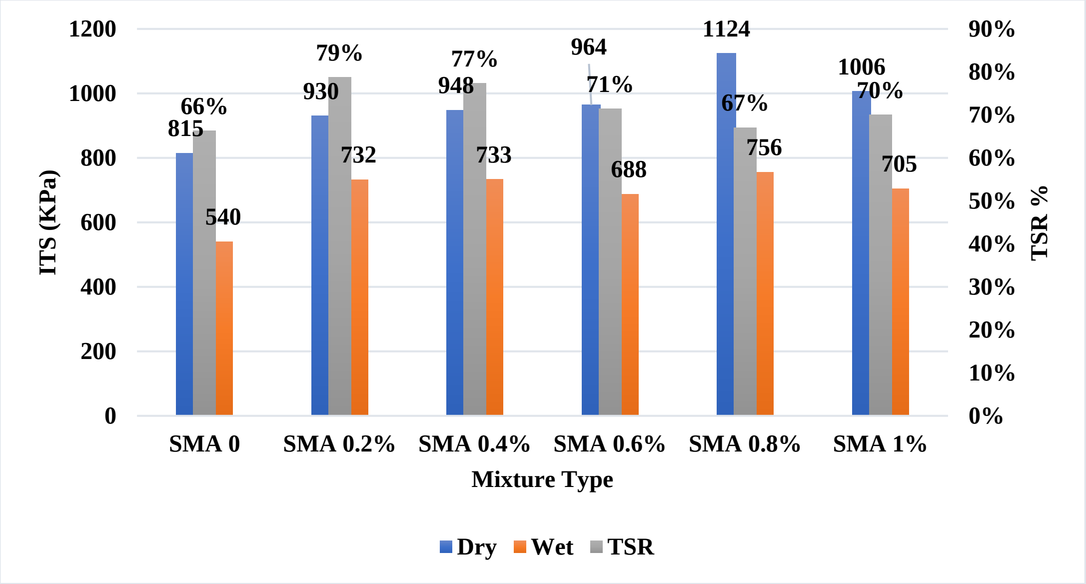


Figure 4.15: ITS and TSR of Control and Modified SMA Mixture.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the laboratory work, conclusions can be drawn:

a. Employing an unmodified Stone Mastic Asphalt (SMA) mixture for paving is ineffective, as it fails to meet essential volumetric and mechanical property standards. Particularly noteworthy are instances where the tensile strength ratio falls below 80% and the drain-down rate exceeds 3%.

b. With the use of paper pulp and CKD as additives to the mixture, where these materials are added after mixing them with the emulsion in specific proportions to obtain a material in the form of granules (EPC), and they are added by the dry method to the mixture, the resulting SMA mixture undergoes considerable changes in its characteristics, including the following:

a. Using 0.2%, 0.4%, and 0.6% of EPC modified in SMA mixtures leads to changes in volumetric properties. Compared to the control SMA mixture, where the bulk density and voids filled with asphalt increase while air voids and voids in the mineral aggregate decrease, when using 0.8% and 1% of EPC of the weight of the mixture, the bulk density and voids filled with asphalt decrease while air voids and voids in the mineral aggregate increase, this is because there is different air void in the mixture when compared to the control mixture.

b. The drain down values of all the percentages are decreasing to 0.01% at 160 °C and 0.02 at 180 °C when using 1% EPC-modified.

c. To compare to the normal SMA mixture, Marshall stability increases by 6.7%, 11%, 22%, 33%, and 20% when 0.2%, 0.4%, 0.6%, 0.8%, and 1% EPC modifications, respectively, while flow decreases by 2.5%, 7.5%, and 22.5% when 0.2%, 0.4%, and 0.6% EPC and begins to increase to 2.5% and 12.5% at 0.8% and 1% EPC.

d. The use of EPC modifiers is due to the increase in tensile strength (ITS), with the greatest being 0.8% EPC.

e. TSR improves by 19%, 16.7%, 7.15% and 6% when 0.2%, 0.4%, 0.6%, and 1% EPC are used to modify the SMA mixture, while the other mixing ratios of 0.8% show a negative effect on resistance to water damage.

f. Compared to un-reinforced samples, SMA samples incorporating various EPC exhibit significantly greater skid resistance.

The following recommendations are made according to the results obtained from the laboratory work; they can be listed as follows:

a. The use of Stone Mastic Asphalt (SMA) mixture composed of local materials is recommended as a preventive maintenance method to enhance pavement efficiency.
b. The utilization of wastepaper and cement kiln dust added through the dry method is strongly recommended.
c. It is recommended to use ordinary Portland Cement (OPC) as a percentage of the mineral filler for the SMA mixture rather than CMF to obtain better resistance against water damage.
d. The use of waste materials as modifiers in the asphalt industry is recommended, given their cost-effectiveness and their potential to contribute to environmental protection.

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