

Chapter 1

INTRODUCTION

1.1 Prologue

This chapter provides the brief overview of fatigue cracking in asphalt pavements and the various factors associated with it. The importance of asphalt mixes as a surface course is discussed followed by the problems related to asphalt pavements. Also, the mitigation measures that can be adopted for the improvement of pavement performance are highlighted. The next section is focused on the outline of fatigue cracking, its causes, crack propagation, and the importance. The significance of asphalt mastic in dictating the fatigue behavior of asphalt mixtures is presented next followed by the discussion on role of fillers in the mastic. In addition, the necessity of choosing proper test and testing geometry for accurate fatigue characterization of asphalt mastics is also discussed. The last section enlist the current research gaps, goals and objectives and concludes with the thesis organization.

1.2 Fatigue Cracking in Asphalt Pavements

Asphalt pavement has always been a primary choice of engineers and policymakers due to reduced traffic noise, cost efficiency, and better safety and comfort [1]. It has low flexural strength and hence resists the load by transferring it to lower layers via grain-to-grain contact between the aggregates in the granular structure. It is a multi-layered system consisting of a surface course, binder course, base course, sub-base course, and subgrade starting from the top. The surface course is directly exposed to the wheel loads and the environment, due to which it is most susceptible to distress. Therefore, the asphalt mixtures used in the surface course are preferred to be of the best quality having sufficient stability and durability that can sustain the

anticipated load as well as withstand the distresses such as rutting, shoving, raveling, bleeding, slippage, corrugations, depressions, fatigue, potholes, etc. [MS-2]. The premature failure of pavements in India is a critical concern for engineers and contractors. Indian Roads Congress (IRC) in collaboration with different research institutes worked on design guidelines to understand pavement distresses, their causes and eventually the implementation of mitigation strategies for improvement in pavement performance. For example, despite of being the most commonly used binder in India, efforts are made to replace VG-30 with VG-40 binder in hot climatic regions [2]. Also, to keep pace with the increasing traffic loadings, heavier truck weights, new axle designs and increased tyre pressures, the upgrade in asphalt technology in the form of binder modification has been proven as performance enhancer in asphalt mixtures [3,4]. The most popular mode of bitumen modification is in the form of polymer modified binder (PMB) and crumb rubber modified binder (CRMB) is also promoted owing to the superior performance of asphalt mixtures prepared with modified binders.

The deterioration of the material due to the repeated loading characterized by a reduction in stiffness and strength, ultimately leading to failure, is known as fatigue [5]. Understanding the fatigue mechanism in connection to road pavement performance is necessary to protect the significant value invested in road pavements. It is one of the primary causes of distress in asphalt pavements, resulting in the deterioration of pavement materials and, eventually, the pavements [6]. Insufficient pavement structure, excessive traffic load repetitions, and use of fatigue-prone asphalt mixtures are the primary causes of fatigue distress in asphalt pavements [7]. The crack manifestation is initially in the form of thin and sparsely distributed longitudinal cracks in the top layer. These cracks are joined by transverse cracks as the deterioration increases forming an interlaced pattern known as alligator cracking. The fatigue cracking deteriorates the structural capacity and surges the maintenance expenditures of the pavement. Moreover, it can act as a deteriorating medium by allowing the water and aggressive agents to

infiltrate the unbound layers, hence accelerating the deterioration. Thus, properly understanding and considering fatigue damage while designing asphalt pavements is crucial.

1.3 Role of Filler

Broadly, the aggregate particles in the Hot Mix Asphalt (HMA) are subdivided as coarse aggregates (retained on a 4.75 mm sieve) and fine aggregates (passing a 4.75 mm sieve). They occupy approximately 85% of the volume within the asphalt mixture and form the skeleton of HMA [8]. The mineral filler, which are aggregate particles passing a 75 μm sieve, is more often considered as an asphalt binder stiffening agent or modifier rather than aggregates [9]. The fillers constitute up to 12% by weight of the total mix in asphalt pavements depending on the mix design [10] and hence are an important factor affecting the performance of the mix. The filler serves several purposes in the asphalt mixtures, such as a) void filling in the aggregate skeleton; b) enhancement in the stability of the mix; c) fulfilling the aggregate gradation requirements; d) strengthening the bond between aggregate and asphalt binder; e) stiffening of asphalt; f) extending the asphalt, i.e., increasing the asphalt volume, etc. [11–13]. Mineral filler, in combination with asphalt binder (which is a viscoelastic material acquired through fractional distillation of crude oil), is referred to as ‘asphalt mastic’ and significantly affects the performance of HMA [14,15]. So, asphalt mastic can be considered the actual binder that provides cohesion to HMA and keeps the aggregate particles together [16,17]. The fillers play a prominent role in the performance of asphalt mastics since the crack initiation and propagation are widely affected by the properties of the fillers [18,19]. The performance of asphalt mastic is a primary function of the filler incorporated in the asphalt mastics [20]. Zhang et al. [21] investigated the feasibility of utilising the red mud (RM) derived mineral filler in place of commonly used limestone in asphalt mastics. The inclusion of RM improved the elastic recovery but the effect on fatigue resistance was detrimental. Frigio et al. [22] demonstrated that the filler stiffening effect is more pronounced over mineralogy of filler and

the type of bitumen. Vale et al. [23] and Mazzone et al. [24] showed that the fatigue resistance become independent of consistency of bitumen at high filler content. Zhu et al. [25] concluded that the high filler content causes inhomogeneity as well as the random evolution of damage in the mastics. The same concern was expressed by Micaelo et al. [26] in their study by showing the faster damage rate in stiffer mastics. Peebles et al. [27] concluded that the addition of filler in PMB increases fatigue life by 345% whereas decrement in fatigue life observed for neat binder mastic (85%). Hence, the choice of fillers and the filler content is a judicial decision for the fatigue performance of the asphalt mastics as well as the asphalt mixtures especially with the waste fillers whose properties are not very well explored previously.

1.4 Importance of Asphalt Mastic

The, asphalt mastic is the combination of mineral filler and asphalt binder, which are fused at the particular F-B ratio, owing to its performance to the components. It is the weakest phase of an asphalt mixture and plays a primal role in every aspect, from mixing to laying and throughout their service life. The resistance to distress like fatigue, rutting, thermal cracking, and moisture damage has been affected by the quality of asphalt mastics; therefore, it needs to be addressed primarily [28–35]. The primary role of asphalt mastics in dictating the performance of asphalt mixtures has been highlighted by various literatures [36–39]. The crack initiates from the mastic phase which makes it even more critical component of the mix. The laboratory characterization of asphalt mastics is not very popular as compare to the asphalt binder. In general, only the properties of asphalt binder are explored either by physical tests or by the rheological testing using dynamic shear rheometer (DSR). Therefore, the available literatures on the laboratory testing of asphalt mastics are very limited with respect to that of binder. Being the actual binder, the precise fatigue characterization of asphalt mastics may provide insight into the behavior of asphalt mixtures and eventually the pavements.

1.5 Fatigue Testing

The Time sweep (TS) test has been considered the most accurate fatigue test for asphalt binder/mastic because of its exact simulation of the pavement conditions but it is not considered very practical owing to the extensive testing durations. The linear amplitude sweep (LAS) is currently the most popular fatigue test for the asphalt binders but its suitability as an alternative of time sweep test for the fatigue characterization of asphalt mastics is not explored. Moreover, the fatigue testing of asphalt binder/mastics is conducted through DSR by using a conventional parallel plate cylindrical geometry (CG). However, recent studies have shown that the CG is not very suitable for the testing of binder/mastic [17,40–42] due to which a global geometry such as hyperbolic geometry is needed that can precisely characterize the fatigue damage in asphalt mastics. The in depth study on the recently introduced hyperbolic geometry is not available that can provide a detailed information about the damage evolution with the applied loading. Since, the asphalt mastic is the combination of filler and the binder which are mixed together in a certain proportion, the performance of asphalt mastics is dependent on its constituents. In addition, there are other testing related variables which directly affect the behavior of mastics. Previous literatures have highlighted several factors affecting the performance of mastics [9,10,43,44] but an integrated study assimilating all the major factors can provide the major insight into the behavior of asphalt mastics.

1.6 Research Gaps

This study attempted to address the following research gaps by utilizing different waste fillers to prepare asphalt mastics and conducting the LAS testing on cylindrical and hyperbolic geometry at various testing conditions, followed by the simulation of asphalt mixtures.

- A wide variety of natural fillers have been used in the HMA, out of which Limestone is the most commonly used mineral filler [45]. But the massive and long term usage of natural

fillers is not feasible from the aspect of sustainable development. Therefore, more focused researches are needed on exploring the waste fillers so that they can be utilized in actual construction practices.

- Previous studies have majorly focused on the fatigue analysis of asphalt binders. The SHRP guidelines also emphasized the importance of binders in the performance of asphalt mixtures. But the binder exists in the fused form along with mineral filler, collectively known as asphalt mastic. The composition and behavior of the asphalt binder and asphalt mastic are different and, therefore, cannot be used interchangeably for testing. Hence, the mastic should be recognized as the actual binder inside the asphalt mixture. The asphalt mixture can be visualized as the aggregate skeleton coated by the asphalt mastic, not the asphalt binder. The asphalt mastic can give more accurate information about the performance of the asphalt mixture and, eventually, the asphalt pavements. Therefore, the research should be more focused on the behavior of mastic under different testing conditions.
- The drawbacks associated with the Superpave fatigue parameter and the time sweep have encouraged the researchers to adopt the LAS test for the fatigue analysis of asphalt binders. However, its efficacy in determining the fatigue characteristics of asphalt mastics is still not well explored. The LAS test, which is the most popular testing method due to its lesser time duration and better repeatability, can be a finer alternative to the TS test, but its potency in the case of asphalt mastics has not been explored yet.
- The cylindrical geometry is the most common geometry used across the globe due to its simplicity and availability in most DSRs. But, researchers from time to time have highlighted the issues associated with it, such as non-uniform stress distribution [46], incompetency in large particle size modifiers [42], inaccuracy in the test results [142], etc. In view of this, various alternate geometries have been experimented such as cone-plate

[41], bob-cup [42], torsional cylinder [47], dog bone [48], vane [49], parallel hollow plate [214], etc. Hence, there is an immense need to find a geometry that gives accurate fatigue properties of the asphalt mastics and can be universally accepted.

- The behavior of any composite is dictated by its constituents; the same is true for asphalt mastics. The response of the asphalt mastic to any loading condition is dependent on the properties of the mineral fillers (physical and chemical), properties of the asphalt binder (chemical and rheological), and the relative proportion of filler and binder (denoted as F-B ratio). In addition, the testing conditions such as temperature, geometry, and analysis approach also dictate the material's behavior. Hence, a comprehensive study covering all the aforementioned variables is required, which can only precisely evaluate the performance of asphalt mastics and the factors affecting it.
- The filler content in the chosen gradation varies to a wide extent. The optimum filler content that yield superior performance and require lower binder quantity is desirable by virtue of which the selection of filler content is a judicial decision. Therefore, a methodology is needed that can optimize the filler content in the asphalt mixtures.

1.7 Goals and Objectives

This study is pivoted on the fatigue evaluation of the asphalt mastics as well as the asphalt mixtures. The objectives of the study are outlined as follows:

- 1) To explore the morphological characteristics of different fillers to determine the most influential parameters responsible for the behavior of fillers.
- A wide range of tests has been conducted on the fillers to obtain the different parameters attributed to the performance of mineral fillers.
- 2) To assess the applicability of an accelerated fatigue test like the LAS test as an alternative to traditional fatigue tests, i.e., the TS test.

- The TS tests take an unpredicted time duration that can take a few minutes to several hours, which is not feasible; hence an accelerated test with similar testing results can serve the purpose.
 - 3) To investigate the efficacy of hyperbolic geometry as a superior alternative to conventional cylindrical parallel plate geometry.
- The criticism of cylindrical geometry due to its flaws, as described in numerous works of literature, motivated the authors to explore new geometry in the form of hyperbolic geometry.
 - 4) To study the variation in fatigue performance of asphalt mastics with respect to the primary variables associated with them.
- The change in the fatigue characteristics of asphalt materials is studied with the change in testing temperature, filler content, type of binder, filler type, type of geometry, analysis procedure, applied strain, etc.
 - 5) To optimize the filler content based on fatigue performance and economic aspects.
- A methodology for selecting the optimum filler-binder ratio from the properties of fillers and binders is proposed based on the fatigue performance of asphalt mixes and optimum binder content.

1.8 Organization of the Thesis

The current research has been fractionated into 8 different chapters described as follows:

Chapter 1: Introduction

This chapter briefs the background of the study, starting with the importance of the transportation sector for the nation's overall growth. The current stats of highway construction are described next, followed by the need for sustainable pavement construction technologies. A brief introduction to fatigue cracking in asphalt pavements is presented, and the importance

of asphalt mastics is highlighted. The goals and objectives of the study are enlisted with a summary. Finally, the chapter concludes with the details of the thesis organization.

Chapter 2: Literature Review

This chapter clubs the major state-of-the-art information associated with the study. A detailed description of the components of asphalt mastics and their importance is provided. The section thoroughly discusses the fundamentals of rheology and the mechanism behind the functioning of DSR. A comprehensive discussion on fatigue cracking and the major fatigue testing methods in mixtures and binders/mastics is presented next. Also, different types of testing geometries are presented in detail, along with their feasibility. The chapter concludes with the problem statement and the identified research gaps.

Chapter 3: Research Methodology

A summary of the research methodology of this study is presented in the form of flow charts. The study has been divided into different phases, and the outline for the same is discussed in this chapter.

Chapter 4: Filler Characterization and Design of Asphalt Mastics

The chapter starts with a brief introduction of all the fillers used in the study. The different physical, morphological, and chemical filler characterization tests are discussed in detail, along with respective testing procedures. The next section briefs about the preparation procedure of asphalt mastics followed by the aging protocols. The correlation analysis among various characterization tests has been done to identify the most influential parameters in the performance of fillers. The applicability of Strategic Highway Research Program (SHRP) binder criteria to the asphalt mastics has also been examined, and a new relationship between LVE strain and LVE complex modulus is presented.

Chapter 5: Alternate Fatigue Test and Testing Geometry

This chapter presents the analysis used for assessing the suitability of an alternate fatigue test as a surrogate for the time sweep test. In addition, the efficacy of using hyperbolic geometry in lieu of conventional cylindrical parallel plate geometry is also investigated. The mathematical derivations of the correction factors employed for calculating different rheological parameters in hyperbolic geometry are also presented in detail.

Chapter 6: Factors Affecting the Fatigue Behavior of Asphalt Mastics

The comprehensive evaluation of the various factors which dictate the performance of asphalt mastics has been detailed in this chapter. The effect of temperature, filler-binder ratio, type of filler, binder, and applied strain levels is discussed in this chapter.

Chapter 7: Performance Evaluation of Asphalt Mixtures

A detailed discussion on the evaluation of asphalt mixtures using the modified Marshall Method of mix design has been presented in this chapter. The physical testing of the constituent's aggregates and the brief testing procedures are explained. The determination of optimum binder content (OBC) for all the fillers at different filler contents corresponding to both types of binder (VG and PMB) is also presented. The fatigue performance of the asphalt mixes using the fracture test, i.e., the SCB test covering various aspects of sample fabrication, such as cutting, notching, and conditioning, is also the basis of this chapter. The methodology for selecting the optimum filler content from the filler and binder properties resulting in the higher fatigue performance and lower optimum binder content is presented next to culminate the chapter.

Chapter 8: Conclusions, Discussions, and Future Scope

The primary conclusions satisfying the objectives of the study are summarised in this chapter.

The novelty of the work highlighting the contribution has also been outlined. The chapter concludes with the recommendations and future scope of the study.

