CHAPTER 1
Introduction

1.1. BACKGROUND

In the early 1800s, the famous Prairie Schooner, the icon of the western expansion period, took eleven months to cross America. It served as fortress, ambulance, boat, and home for those making the trip. On August 31, 1903, a Packard automobile ended a 52-day journey from San Francisco to New York, the first time an automobile crossed the continent under its own power. Today, as we approach the new millennium, we have a wide variety of transportation choices, including commercial airliners, trains, automobiles, subways, buses, motorcycles, motor homes, ships, boats, and even bicycles! Philip Guedalla said in his book The Hundred Years, "The true history of the United States is the history of transportation." One can only wonder if the strategic planner riding in the Prairie Schooner imagined the trip in the Packard or if the driver of the Packard fantasized about flying across America in hours or being virtually transported across cyber networks in seconds.

The U.S. transportation system carries over four trillion passenger miles of travel and 3.7 trillion ton miles of domestic freight generated by more than 260 million people, six million business establishments, and 87 thousand government units. The transportation sector of the United States' economy has remained close to 11 percent of the gross domestic product (GDP) for several years at a level of $775 billion annually (U.S. Department of Transportation, 1999).

A major part of the U.S. transportation system is the world largest highway system. The United States has over six million kilometers of public roads with more than 60% classified as flexible pavement and the remaining shared between rigid, aggregate, surfaced and composite pavements (U.S. Department of Transportation, 1999).

1.2. HISTORICAL DEVELOPMENTS

The first roads were probably developed from animal tracks, where the only construction was of route markers to avoid marshes and other inhospitable features (Hindley, 1971). These tended to hold to high ground, such as on the Downs in the United Kingdom, to allow the traveler clear vision and, hence, safety. As men became more settled, genuine construction began to be incorporated by clearing the route. Removed stones were often used to build lines of cairns, or even low walls, which served to mark the road. In some parts of the world, the construction even went as far as to include artificially leveling the road, building embankments, and digging ditches.

The earliest paved roads tended to be block paving in urban areas. Block paving appears to have started in the Middle East, with bitumen being used for brick and stone bonding as early as 3200 BC. However, constructed roads became necessary only when society was based in cities, so fully constructed roads did not emerge until the ancient empires arose, in particular the Roman Empire. Roman roads were not all constructed in the same way; the construction method depended on both the local conditions and importance of the road. For major roads, the ground was usually leveled and aggers or drainage ditches were dug along both sides of the road. After the fall of the Roman Empire, the importance of cities diminished and the need for roads declined, nor was there an organization capable of constructing and maintaining them. Therefore, there was little true road building during the Middle Ages until the Industrial Revolution and the general movement away from an agrarian economy. In the United Kingdom, the leading figures in this era that contributed to the construction development were Thomas Telford (1757-1834) and John Loudon Macadam (1756 - 1836).

The construction method developed by Telford had a layer of uniformly large stones as the foundation, overlaid by smaller graded aggregate that was carefully washed and sieved prior to use. Macadam also used carefully graded aggregate, but omitted the base layer of large stones. The pavement surface of roads by both were moderately cambered with the gradings being selected so that the surfacings would be sealed with the dust produced by heavy, slow-moving horse-drawn wagons filling any exposed gaps. The overall structure of Telford's pavements was relatively thick and strong, while that of Macadam's pavements was cheaper and less robust.

While the vehicles were powered by horses, the main interest in surface characteristics was in the smoothness of the surface. However, the higher speeds that arrived with the automobile caused the finer particles to rise, resulting in great clouds of dust. Initially, means to reduce the dust included the use of water-bound 'macadams', but the most successful way was to bind it with tar. The idea of pre-mixing the aggregate skeleton, or 'macadam', with tar binder was first tried in the 1830s. Tar-macadam became so popular in the early twentieth century that all asphalt was called 'tarmac'. This term became increasingly inappropriate because bitumen replaced tar as the most common binder for asphalt paving materials.

Other asphalt materials were developed that gave impermeable surfacings that would produce no dust as well as resist permanent deformation. Trinidad Lake asphalt was used to produce an asphalt or mastic mortar, generally used on city streets. The addition of a proportion of larger sized aggregate to bulk up the mortar resulted in the concept of rolled asphalt, with the predominant binder changing through pitch bitumen to petroleum bitumen.

Refined binder has exceeded natural asphalt use in roads since 1902. However, since the 1973 oil embargo, numerous field construction and maintenance personnel throughout the United States have claimed that asphalt binders have changed and that these changes have resulted in construction and early-life performance problems in asphalt concrete mixtures. Some engineers believe that asphalt "is not what it used to be." The general belief of field personnel is that the oil companies are taking the "goodies" out of the asphalt and using them as feedstock for the petrochemical industry. Traditional asphalt specification tests do not identify the important properties that control pavement performance.

Field engineers often face problems such as placement difficulties (tender mixes), excessive deformation under traffic (low stability), thermal cracking, raveling, and stripping (water susceptibility) of asphalt concrete pavements. These problems result in higher maintenance costs, shorter service lives, higher life-cycle costs, and public frustration.

Advancements in polymer technology have resulted in its use in binder to enhance its performance. At first, the use of polymers was based mainly on empirical criteria, and polymers were found to not be a general solution for all problems. Indeed polymer modifications were found to improve binder performance in most cases, but this performance was strongly related to the content and type of modification.

The effectiveness of polymer modification on enhancing binder performance was not recognized by all investigators. While significant improvement in rutting resistance was reported by many researchers (Little, 1992; Khosla, 1991), others found no significant improvement (Al Dhalan *et al.*, 1992). In other cases, reverse effects due to polymer modification were reported (Brown *et al.*, 1992). Unless a suitable type of modification for each problem is carefully studied, reverse effects of this process would be left to chance.

It has been recently reported that 48 commercial brands of asphalt modifiers are currently used, which can be classified into six categories: fillers, extenders, thermoplastic polymers, liquid polymers, aging inhibitors, and adhesion promoters (Peterson, 1993). Most of these modifiers have not been evaluated comprehensively. Like most other technological developments in civil engineering, polymers were first used based on field experiences, with a limited understanding of the relationship between resultant structure and physical and chemical properties. Due to the chemical complexity of the subject, several questions still remain unanswered, leaving pavement engineers in the dark about how to select the suitable modification for each particular problem. These questions can be summarized as follows:

- Type and extent of modification that one should use for each application.
- Effect of short- and long-term aging on the polymer-binder blend.
- Possible reverse effects of the modification.
- Chemical and physical stability of modified binders with temperature and loading.
- Applicability of the current test methods to polymer-modified binders.
- Applicability of the Time-Temperature Superposition Principle to polymer-modified binder.
- Modified binder-aggregate interaction in Hot Mix Asphalt (HMA).

- Development of adequate models to fit the viscoelastic properties of modified-binders.

1.3. PROBLEM STATEMENT

Asphalt binder is a viscoelastic, thermoplastic, arrheodictic material that is characterized by a certain level of rigidity of an elastic solid body, but at the same time, flows and dissipates energy by frictional losses as a viscous fluid. Adding a polymer to this complex material results in a two-phase system that can experience all types of behavior depending on the polymer content and mixing process.

A theoretical viscoelastic model that can fit this complex behavior is needed for a number of reasons. First, this model would allow pavement engineers, specification writers, and researchers to calculate the modulus, phase angle, and other rheological properties for a wide range of loading times and temperatures from measurements made at limited loading times and temperatures. Secondly, parameters that describe the time and temperature dependency of the rheological properties are essential for relating physical behavior to binder chemistry (Marasteanu *et al.*, 1996). Finally, such a model could further help the understanding of the polymer-binder interaction and control the final properties of the blend.

1.4. OBJECTIVES

The objective of this study is to develop a model to fit the dynamic behavior of straight and polymer-modified binder based on actual experimental data performed on unaged binder, short-term aged binder, and long-term aged binder. This model shall describe the linear viscoelastic behavior of both polymer-modified and regular binder using a limited number of parameters. This requires modeling experimental responses in a consistent way and in accordance with the linear theory of viscoelasticity.

1.5. SCOPE

To achieve the objectives of this study, an experimental program was designed to investigate the temperature, loading time, and aging effect on the asphalt-polymer blend. The materials studied were selected based on compatibility and availability. The polymer-modified binders were prepared in a previous study conducted by Fariborz Gahvari (1996) at Virginia Tech. Four different modifiers were available. Styrene Butadiene Styrene (SBS) was selected in order to investigate its effects on binder performance because it is the most common modifier used in the asphalt industry. Styrene Ethylbutylene (SEBS) was selected because no conclusive data are available on its effects on binder performance. Also, three other binders widely used in the commonwealth of Virginia (PG 64-22, PG 70-22, PG 76-22) were selected.

Since this study is restricted to the linear region of response, strain sweeps were conducted to determine the linear viscoelastic region. Frequency sweeps were performed at the target strain. The isochronal plots were then shifted to a reference temperature to construct the master curves, and the validity of the Time-Temperature Superposition Principle was investigated.

To develop the mathematical models, it was decided to characterize the binder response using the absolute value of the complex shear modulus ($|G^*|$) and the phase angle. By using these two models, any other viscoelastic functions of interest can be obtained. The models were developed using the matching function approach. The resulting models were then validated by comparing them to actual experimental data.

This thesis is comprised of six chapters. Chapter 2 presents a background and an overview of the subject. This includes discussion of conventional tests, the Superpave^{TM} binder specification system, and models used to characterize asphalt binder rheology. The process of selecting the materials and the equipment used in the Dynamic Mechanical Analysis (DMA) of asphalt binders are introduced in Chapter 3, which also investigates the construction of master curves to evaluate the effectiveness of previous routines and to select the more appropriate method for shifting. Chapter 4 presents the theoretical derivation of the proposed models. Chapter 5 presents the evaluation and validation of the proposed models using experimental data. Chapter 6 presents the summary, findings, and conclusions of this study along with recommendations for further research.