Sustaining a Three Trillion Dollar Ubiquitous Asset

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Introduction

Whether it's commuting to work, traveling to school, shopping for groceries, or going on a vacation, transportation is ingrained in our day-to-day lives. Yet very rarely do we think about the roads that make it possible for private, public and commercial vehicles to get from one place to another. Our transportation infrastructure is worth about three trillion dollars, or about one-third the value of all fixed assets in the United States, and includes about 2.5 million centerline miles of highways paved using asphalt mixtures.[1] Its social, economic and environmental impact cannot be overemphasized. Just how much is 2.5 million centerline miles of asphalt? Think of it this way: it would take about 10 seconds at the speed of light to cover this distance, or roughly five trips to the moon and back. It is an extraordinarily difficult task to develop and deploy engineering solutions and practices that can be used to maintain and expand our roadways in a sustainable and eco-friendly manner. The research program on pavements and pavement materials at UT-Austin is just one piece of a massive undertaking by the transportation industry to achieve this.

Need for Research on Pavements and Materials

The very first successful application of asphalt to pave a road was in front of the city hall in Newark, New Jersey in 1870.[2] Pennsylvania Avenue, in Washington D.C., was paved in 1876 – and we have not stopped paving since. A pertinent question would be: what research and technological advances are needed for a material that has just two ingredients and has been in use for more than 140 years? To answer this question, we must first recognize that although all asphalt roads look alike, each road is uniquely engineered and designed to meet the demands of the local traffic loads and speed. Asphalt mixtures used in the construction of asphalt roads are made up of two non-renewable materials: bitumen produced from crude oil

Figure 1. Construction and Maintenance

(typically 5% by weight) and mineral aggregates mined from stone quarries (typically 95% by weight). The bitumen in the asphalt mixture acts as a glue to hold the mineral aggregates together.

The chemical and engineering properties of bitumen vary significantly depending on the crude oil used to produce the bitumen. Bitumen produced by different oil refineries are frequently modified and engineered to meet the demands of specific applications; bitumen that is appropriate for use on an interstate may not be appropriate for a local street. Similarly, bitumen used on an interstate in Texas may not be appropriate for use in Oklahoma. The mineral aggregates used are almost always locally acquired from a source not too far away from the construction site. Depending on the geographical location, the mineral aggregates used to produce asphalt mixtures for road construction can have very different physical and chemical characteristics. Due to the variability associated with these two ingredients, asphalt mixtures and pavements need to be uniquely designed for each construction job. Bitumen proportion that is only one-half percentage point more or less than optimal can result in a prematurely failed roadway and millions of dollars in losses. Research and education in this area is driven by the need to reduce the life-cycle cost of roadway construction and maintenance, promote environment friendly and sustainable practices, and develop a trained workforce to incorporate state-of-the-art research into practice.

Construction and Maintenance Costs

The costs associated with the construction and maintenance of roadways are fairly significant and typically borne by tax payers. For example, a highway expansion from four lanes to six lanes can cost approximately $4 million per mile. Resurfacing to maintain an existing four-lane road costs about $1.25 million per mile.1 Improperly designed and constructed roads not only require frequent and expensive maintenance but also result in economic losses for their users. For example, one study conducted a few years ago demonstrated that it costs the states approximately $1.2 billion annually to fix crumbling roads and highways. At the same time, it cost drivers using these roads approximately $4.8 billion to cover damage and other costs associated with driving over poorly maintained roads.[3] Since typical asphalt mixtures used in maintenance and construction consume non-renewable material resources, these costs continue to rise. In addition to depleting material resources and rising costs, another challenge is the disproportionately increasing demands on the roadways. For example, between 1980 and 2006, truck miles travelled increased by 106% and automobile miles travelled increased by 97%. During this same period of time, highway lane miles increased by only 4%.[4] In other words, the materials and roadways designed and built today are expected to take much more traffic volume than a few years ago and last longer.

Modest advances in the life-cycle and maintenance costs of roads can translate into significant savings of taxpayer dollars and non-renewable materials used for these activities. For example, in one of our research studies we developed a simple technique based on scientific principles to identify the best bitumen source for a given mineral aggregate that will result in a durable asphalt mixture.[5] A simple analogy to understand the impact of this research is as follows: If you need to glue two pieces of metal you will get the best results by selecting the kind of glue that is designed for metal surfaces. In other words, you would want to find and use the most appropriate kind of glue available in a hardware store for a given application. Bitumen acts as a glue to bind aggregate particles in a mixture. Although bitumen produced by different refineries look the same, they have very different physical and chemical characteristics depending on the source of the crude oil used to produce the bitumen. Through our research we were able to develop a methodology that could be used to identify the type of bitumen that worked best with a given mineral aggregate. By optimally pairing bitumen with mineral aggregates from different sources, it is possible to significantly reduce the risks of premature road failure and reduce its life-cycle cost.

Another example of a research study to help reduce the life-cycle cost of our roads is investigating methods to engineer high performance bitumen through chemical or physical modification. One of the ways in which roads fall apart is due to the formation and growth of cracks. These cracks frequently start as micro-cracks due to the action of traffic loads or temperature fluctuations. The micro-cracks form within the bitumen that holds the mineral aggregates together. Due to the semi-solid nature of bitumen, these small micro-cracks can also self-heal if the road is allowed to "rest" for a short period of time without any traffic loads.[6] Our research is trying to create a knowledge base that links the chemical makeup of bitumen to its ability to resist cracking and promote self-healing. This knowledge base will make it possible to modify the chemistry of the bitumen in a way that would make it inherently more resistant to cracking and also to have superior self-healing characteristics.

Eco-Friendly and Sustainable Practices

Advances in asphalt technology have made it possible to build and maintain roads that are long-lasting, safe, eco-friendly and that reduce our dependency on non-renewable material sources. Among these advances are asphalt mixtures with high-recycled asphalt content. In fact, asphalt mixtures are the most recycled material in the United States. Not only are old asphalt roads routinely ground and recycled for the construction of new roads, but other "waste" materials such as recycled asphalt shingles and ground tire rubber can be used in new asphalt roads. For example, approximately 60 million tons of asphalt mixture and 1 million

Figure 2: Hot Mix and Warm Mix

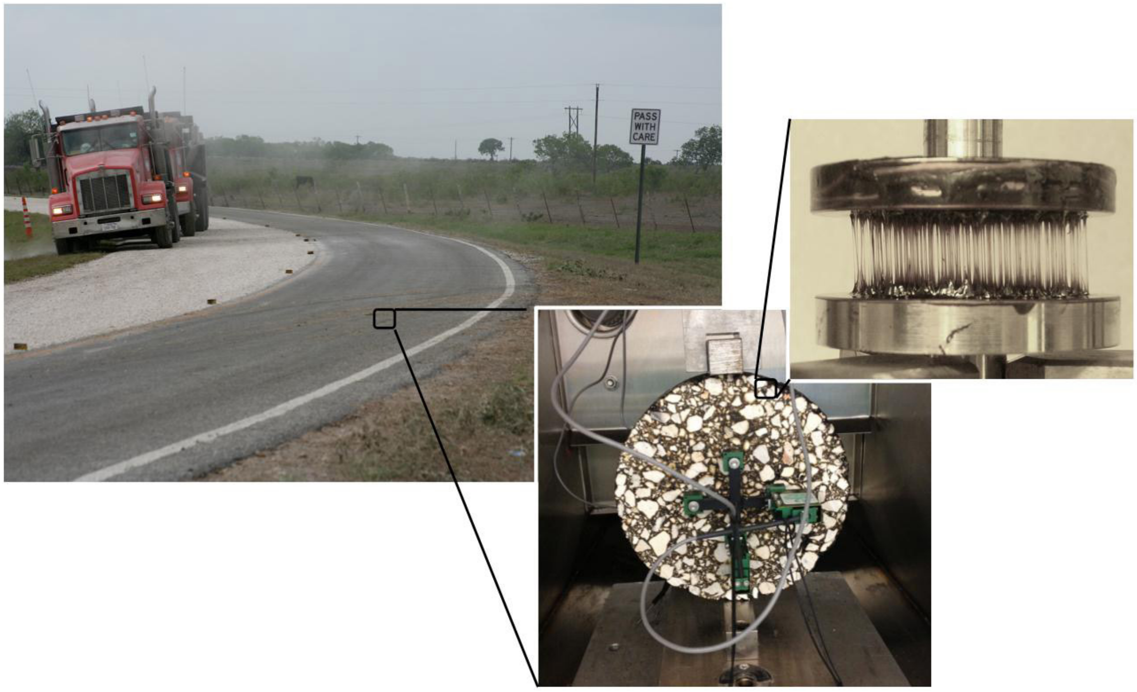

Figure 3: Evaluating the performance of asphalt material at different length scales

tons of asphalt shingles are recycled and used in the construction of asphalt roads saving about 20 million barrels of bitumen.[7] In addition to recycled materials, the traditional asphalt mixture production technology is now being replaced with "Warm Mix Asphalt" or WMA. This technology consumes less energy during the both the production of asphalt mixtures and the construction of asphalt roads. It also reduces the risk and exposure of construction workers to harmful emissions during road construction.[8]

The use of recycled asphalt mixtures, recycled asphalt shingles and Warm Mix Asphalt is certainly a step in the right direction to improve sustainable practices in the area of road construction. However, each technology must be carefully weighed against risks for potentially reduced pavement life. One of the attributes that makes designing and working with asphalt mixtures challenging is that the bitumen in asphalt mixture continues to oxidize and age over time. Aging results in loss of ductility of the bitumen and its ability to relax and relieve stresses when the air temperature (and consequently the road temperature) drops. Recycled asphalt mixtures and shingles contain a precious non-renewable material that is being put back to use: bitumen. However, on the down side, the bitumen from old pavements intended for recycling is oxidized and less ductile. Consequently, new asphalt mixtures that contain very high percentages of recycled asphalt can be susceptible to early failure during cold weather conditions. There is a significant impetus to develop techniques and additives obtained using other natural materials or industrial waste (e.g., used motor oil) to help increase the percentage of asphalt that can be recycled and added to a new mix.

As noted above, another eco-friendly practice in the area of asphalt mixtures is the use of Warm Mix Asphalt (WMA). Conventional asphalt mixtures are produced by heating and mixing the bitumen and mineral aggregates at approximately at temperature of 300F or higher. In contrast, WMA entails the use of chemical additives or a foaming technology to produce asphalt mixtures at approximately 50F lower than the conventional mixing temperature. The use of WMA consumes less energy during production and construction. It also reduces emissions from the production plant as well as from the mix during construction. However, one disadvantage of the WMA technology is that because the bitumen is not exposed to high temperatures, it does not oxidize as much. As a result bitumen in a WMA is softer and can result in premature failure due to excessive deformation of the mix along the wheel path. Interestingly, these two eco-friendly technologies – recycled asphalt mixtures and WMA – have shortcomings that can possibly compensate for each other. Whereas WMA results in the mixture being too soft or ductile, the use of recycled materials results in the mixture being less ductile. The highway industry is now trying to combine the use of these two eco-friendly practices in order to produce mixtures that can perform just as well as a conventional asphalt mixture. For example, in a recent study we evaluated these two eco-friendly practices to determine the best possible combinations of additives and recycled asphalt that could be used to construct long-lasting and durable asphalt roads.

Concluding Remarks

Our program at UT Austin's Center for Transportation Research, along with similar programs across the country, represent a community of researchers and educators that are striving to develop and deliver eco-friendly and sustainable practices to construct and maintain our roadways. The challenges to achieve this are significant and require integrating knowledge from diverse fields. Our research program on asphalt materials and roads at UT Austin brings together experts from the areas of Civil Engineering, Mechanical Engineering, Aerospace Engineering, and Physics. In addition to research, an equally critical component to improve sustainable practices in this area is to attract and educate bright young engineers. An educated and well-trained workforce is the only way to take the knowledge from the training grounds of University laboratories to professional engineering practice.

The next time you step out of your home, school, or office building, please take a moment to recognize the science and technology that is continually being developed and implemented to sustain the multi-trillion dollar backbone of our nations transportation system: the ubiquitous asphalt road.

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