Alternatives to Oil-Based Binders for Asphalt Concrete Paving in Northern California

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Every day, millions of Americans travel along highways and roadways during their everyday lives. Many people do not understand the vital impact that this infrastructure has on their day to day activities and what goes into building these roadways. The traditional process of using paving a roadway requires the use of an asphalt binder that is typically an oil-based binder. With the environmental effects of manufacturing and producing these oils, as well as the effects on the environment when the asphalt is placed, there have been a few accounts of producing an alternative asphalt binder that does not use oil. This paper will examine recent use of alternative asphalt binders in paving projects in Northern California and the effectiveness they have on wear life, sustainability, and constructability. The methodology of this paper is that of an action-based research were a case study of a recent paving project will be examined and then built off of to determine the above listed criteria. The research will later conclude that while studies are still early, the use of alternative binder, particularly those of a plastic base, could in turn replace an oil-based binder in aspects of sustainability, function, and constructability.

Key Words: Asphalt binders, Deteriorate, Roadways, Paving, Recycled Plastic

Introduction

In Northern California, there is a massive infrastructure system that has unfortunately been given a C-grade from the ASCE (ASCE, 2019). Within this overall grade, we have received a D grade and currently rank 49th in the nation for worst roads. This is mainly due to having many deteriorating roads that are in need of dire repair. This has cost Californians over $61 billion dollars in congestion related delays, traffic collisions, and increase vehicle operating cost. This deterioration is primarily due to lack of building lasting roadways that will withstand the test of time due to design and material issues.

In 1909, the first street in the U.S. was paved using a crude form of oil and aggregate to make a harder than normal yet smoother and longer lasting roadway (Allen, 2019). Little did anybody know; this would soon be the future of the U.S. infrastructure. While much has changed in the way we produce these roadways from the 1900's, one thing that hasn't changed much is what they are made out of. We are still using the same crude materials of oil and aggregate, heated up and mixed to produce asphalt for our roadways. While the rock hasn't changed much, the oil has and has become more refined and better suited for our typical paving practices.

There are a few concerns regarding the use of oil-based asphalt binders. One being the current shortage of oil not only in the U.S. but around the world. There is a high demand for oil in many industries and it is making increasingly difficult, as well as expensive, to produce asphalt. This last year alone the Northern Californian paving industry saw a 10%-20% increase in asphalt prices due to oil (EIA, 2021).

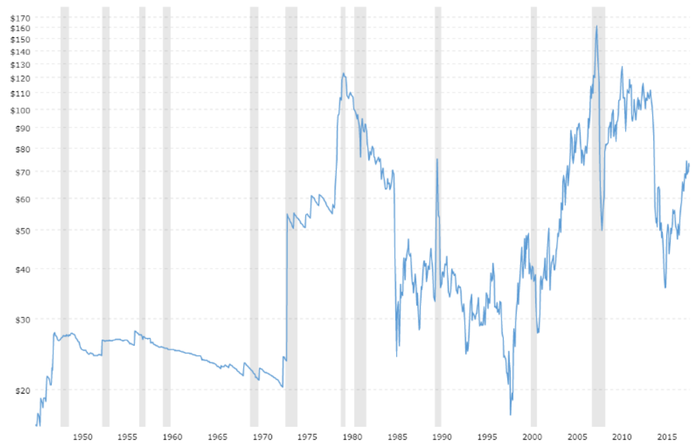

Figure 1 – Crude oil prices per barrel over the past 70 years (Macrotrends, 2021)

Another growing concern for the asphalt industry is that of the environmental affect the oil has on the environment. This concern is not only during the placement and construction phase of the asphalt, but in the acquiring of raw materials to produce the asphalt. A majority of this oil is produced from oil rigs in Texas or offshore oil drills in the Gulf of Mexico (EIA 2021). With this production of oil, we are putting our environments at risk of oil spills or leaks like we have seen in past years.

If we are able to reduce our oil consumption in the construction industry a whole, we will not only see cost savings in materials, but also help set a standard of green construction which is lacking tremendously in the heavy civil construction industry. With the use of an alternative asphalt binder that is more environmentally friendly, this could put the heavy civil industry on the right path. This paper is an action-based research to determine if there is a suitable alternative asphalt binder that could be implemented into the Northern California heavy civil construction industry.

The objective of this research is to:

- Extend overall knowledge of asphalt and its characteristics
- Experiment with and create an alternative asphalt binder suitable for construction
- Determine what the most feasible solution to an oil-based binder could be
- To highlight the importance of always finding a better, more sustainable product.

Background

Before diving more into alternative asphalt binders and how they could perform compared to a petroleum or oil-based binder, it is crucial to understand what the later actually is. When it comes to asphalt concrete there are two main components: aggregate and a binder. Caltrans lists five different types of hot mix asphalt in their 2018 spec and they all consist of different ratios of binder and different size of aggregate.

PG 64-16

The most commonly used asphalt in Northern California is Hot Mix Asphalt Type A, otherwise known as HMA-A (Caltrans, 2018). For the purpose of this research, we will be primarily focusing on this blend of asphalt concrete. This type of asphalt concrete typically uses a PG 64-10 for the Northern California area but has been known to use a PG 64-16 in some cases (Leja, 2006). The PG in the name stands for performance grade and then the first number is the maximum pavement operating temperature in Celsius and the second is the minimum. This helps you narrow down your operating range for the roadway and reduce premature failure. Caltrans had recently adopted this grading system in 2006 where before they were using an AR or age reducing approach for grading.

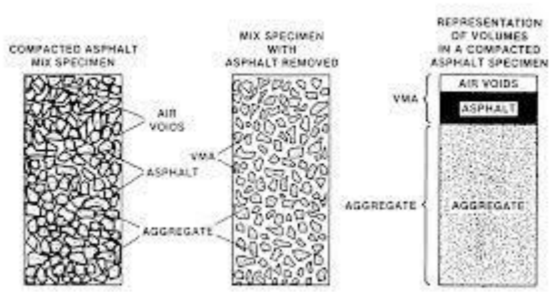

Figure 2 – Volume Diagram of HMA-A (Iowa Dot, 2021)

PG 64-16 is the work horse oil binder for Northern California and was designed to address three different types of deterioration in roadways: permanent deformation (rutting), fatigue cracking, and low temperature cracking (Leja, 2006). This binder was designed to provide enough stiffness in high temperature to mitigate rutting and fatigue, but enough elasticity at low temperatures to prevent low thermal cracking. It also has enough flexibility at intermediate temperatures to minimize fatigue cracking.

While PG 64-16 seems like the overall savior for our below average road grade in Northern California, there are many draw backs that have already been outlined above such as: environmental impact, supply logistics, and increasing cost of crude oil. These issues have been amplified in California as the construction industry here has seen many stricter environmental regulations and a higher increased cost in oil due relative to other states. This has encouraged researchers and contractors alike to investigate alternative asphalt binders that could be more environmentally friendly as well as more readily available and cost effective. Some more well know alternatives include vegetable oil, recycled plastic, and bioorganic materials.

Alternative Binders

When looking at the main three alternative binders, each have their own characteristics and are best suited for different scenarios. Some are also better suited in different regions due to climate and traffic use as well as availability of material.

The most commonly used alternative binder out of the three is vegetable oil as it is a readily accessible material and can be easily substituted for smaller paving operations such as driveways and parking lots (Ji, 2017). Vegetable oil binders are rich in unsaturated fatty acids which are similar to the light oil components of oil binders and can either be implemented as a stand-alone binder or mixed with a traditional oil-based binder for larger production or higher trafficked areas. A vegetable-based binder however would be difficult to implement in Northern California as it primarily targets the fatigue and low temperature cracking resistance in asphalt.

Bioorganic binders are another alternative to an oil-based asphalt binder and are very new to the industry. They are most commonly produced with lignin which is a structural polymer in plants and trees that is released as waste from manufacturing. The binders are created by obtaining different waste streams to achieve the required properties to bind the aggregate together (Allen, 2019). While this binder looks to be a promising environmentally friendly alternative, the logistical issues of sourcing lignin are of concern. There are also limited studies on longevity and deterioration as it is such a new product to the industry.

Recycled plastic is another alternative binder that focuses on reducing the amount of plastic waste as well as creating a longer lasting roadway. The binder is created by taking waste plastic, typically single use water bottles, and melting it down to mix with aggregates and create a pavement material. The use of a recycled plastic binder has also been tested and found to be more durable and last two to three times longer than traditional asphalt paving using HMA-A (Caltrans, 2020). The use of a aplastic binder is effective in mitigating rutting and fatigue due to its hardness at high to mid temperatures. The plastic binder is also forgiving enough in respect to elasticity at low temperatures to help prevent low thermal cracking. It also has enough flexibility at intermediate temperatures to minimize fatigue cracking in highly trafficked areas.

Methodology

To better understand the use of alternative asphalt binders, it is best look at what has been done in the past and build on it. The methodology put forth in this paper is that of action-based research where the information gathered during the literature review will be used to study and experiment with different types of alternative asphalt binders. This approach will focus heavily on hands on experimentation and investigate how effective alternative binders are on wear life, sustainability, and constructability. This research will also draw heavily on industry experience and research that has already been set forth by others. The research and experimentation will be based off a case study of previously preformed project in Butte county Ca where an alternative binder was used to create a recycled roadway.

Analysis

Case Study: HWY 162

One of these new plastic-based asphalt binders is called NEO. This binder is advertised to be more durable and have a higher tensile strength than asphalt while being able to maintain the same flexural properties (Technisoil, 2020). This binder is also more environmentally friendly then the typical Caltrans spec PG 64-16 as there is no leaching into the environment or use of crude materials. It relies solely on recycling already manufactured materials to create the binder.

This liquid plastic binder was recently used on California State Highway 162 in Butte County. An even more unique aspect of this project is that the old roadway was ground in place and then mixed with the plastic binder to create a new roadway that consisted of 100% recycled material (Moherte, 2020). This process not only eliminates 150,000 plastic bottles for a 1-mile segment but reduces the need for trucking material to the site as you are using the existing roadway as the aggregate base material (Moherte, 2020). This process is also eliminating the need to recycle the old roadway and oils contained in it through this process which has become a concern in California in recent years as once the aggregate is mixed with an oil based binder, it can typically only be reused as road base or implemented into more asphalt concrete.

Figures 3 & 4: Butte 162 recycled paving using plastic water bottles (Caltrans, 2020)

Hands on Experiments

One thing that is seen on every construction project is left over materials whether is be scrap plastic pipe or lumber. There is also an abundance of plastic packaging waste throughout the construction process. Out of all the materials used on a construction project, around 10% by weight of the material leaves the site as waste (Bossink 1996). This is tarnishing the reputation of the construction industry as it is far from a sustainable practice. With the new use of plastic asphalt binders, the idea immerged to use plastic construction waste as a potential asphalt binder.

To set upon the testing of the proposed construction waste asphalt binder, the need for an asphalt mixing facility was required. Teichert Aggerates was willing to help conduct this research at their Hallwood Plant in Northern California. The Teichert Hallwood plant produces roughly 350,000 tons of asphalt during a typical construction season and serves mostly to its sister company Teichert Construction (Teichert 2021).

The scrap plastic was acquired from a Caltrans project on State HWY 20 Browns Valley. The plastic consisted of miscellaneous C900 water pipe and HDS storm drainpipe. To make these products suitable for melting into an asphalt binder, they were cut into small enough pieces to fit in a melting pot. Safety precautions were used during the melting process to ensure the safety of all participants such as respirators and safety glasses. Once the plastic melted, it was mixed with a standard ¾" Caltrans HMA aggregate mix consisting of mostly dense graded aggregate. The aggregate was mixed with the melted plastic binder using a shovel in a wheelbarrow and then portioned out into metal cylinders where it was then compacted by hand using a tamper.

Figure 5: Experimental asphalt sample (Jenks, 2021)

These samples were used to show the constructability characteristics of the recycled material binder and compare its workability to that of standard HMA-A using a PG 64-16 binder. The asphalt made of the recycled material was stiffer in nature primarily due to need of more internal heat to keep the plastic liquified as opposed to the oil-based binder which will stay more workable in cooler temperatures.

A standard series of test for HMA-A mix designs per Caltrans 2018 spec includes:

- Air voids content (%)
- Gyration compaction (no. of gyrations)
- Voids in mineral aggregate (min, %)
- Dust proportion
- Hamburg wheel track (min number of passes at 0.5-inch rut depth & Inflection)

These tests where not able to be preformed due to lack of specialized testing equipment. There are also testing methods for production paving which include most of the above listed test as well as compaction testing using a nuclear gauge which was not feasible for this experiment. Therefore, the entirety of testing for this experiment can be labeled as inconclusive as there is not enough information to judge the performance of the recycled binder although it is a constructible alternative. Although these and samples were crude in nature, they show that there is a possibility for the future use recycled construction materials binder just as there is for recycled plastic binders.

Conclusion

As infrastructure across the world continues to grow, so will the need for roadways to accommodate them. While a roadways purpose hasn't changed much since its creation in the early 1900's, the materials and process we use to create these roadways has made tremendous leaps. From the creation of oil-based asphalt binders and now into the use of sustainable binders, there is much for the heavy civil industry to improve and grow on. There is also much room for the heavy civil industry to improve on in the ways of sustainability and cost-effectiveness. The use of an alternative asphalt binder will solve both of these issues and as shown in the HWY 162 case study, is more than feasible. When looking at what this means for the Northern California heavy civil construction industry, this project as well as the idea of using recycled construction plastic as an alternative binder is not to far in the future. The proven success in constructability, performance, as well as sustainability is no doubt a given improvement over the standard oil-based binders that are currently being used in roadway construction

Future Research

There were some aspects in this research and experiment were limited due to the new nature of this topic and push back from the industry as a whole. One point of concern was with how new alternative binders are, there are no long-life studies showing how these binders will hold up performance wise in 30-50 years. It is just to early to say how they will behave although many preliminary studies show they are much stronger and wear resistant. Another aspect overlooked in many studies is that of the effect of reducing these waste materials as a whole. How big of an effect does reducing the amount of plastic used to make a roadway compare to the effort of collecting and transporting said material? Another aspect lacking from the experiment part of this paper is the testing need to measure performance of a recycled construction material binder. Would this binder actually have a greater performance then that of a NEO binder or PG 64-16 binder? Another note of the recycled construction material binder would be the use of multiple different plastics used to create this binder. What would be the correct polymer make up to produce a better preforming product? These are all topics that future researchers should investigate as to better the heavy civil as a whole for generations to come.

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