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How Does Silo Storage Time Affect Pavement Durability in Cold Weather Climates?

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Research Article

How Does Silo Storage Time Affect Pavement Durability in Cold Weather Climates?

—Christopher DeCarlo (Editor: Brigid C. Casellini)

Since its introduction in the late 1800s, asphalt concrete has become one of the most important construction materials in the United States. This basic mixture of sand, gravel, and asphalt binder (sticky, oily, glue-like material) currently covers millions of miles of pavement that connect every corner of the United States. Among the engineering community, asphalt concrete is widely considered the safest, most durable, and most practical material for pavements. Because of its widespread use, many research projects have focused on how to improve the performance of asphalt concrete for everyday use. The many potential variables in the production process have led to research on the effects of these processes on the properties of asphalt concrete.

The goal of my project was to determine how certain asphalt production processes affect pavement performance and durability, specifically focusing on silo storage time. This research was made possible through funding from the Summer Undergraduate Research Fellowships (SURF) program at the Hamel Center for Undergraduate Research at UNH. Ideally, the results will improve our understanding of the effects of plant processes, so that engineers can account for these effects in the design process, leading to stronger and more durable pavements that can effectively resist crack formation, ultimately improving roads, and saving money for the taxpayer.

The author in front of the DCT testing frame at UNH.

So What Exactly is Asphalt Concrete, and Why Study It?

Although one may not realize it, the process of converting raw, naturally existing materials to produce a smooth, safe, and durable asphalt concrete pavement is a complicated and lengthy undertaking. The production of asphalt concrete pavements starts beneath the ground. The primary materials that make up asphalt concrete are aggregates (sands and gravels) and asphalt binder (a byproduct of oil refining). Aggregate is mined from quarries or pits, while binder is a component of crude oil. After these raw materials have been extracted and processed so that they are useful for asphalt concrete production, they are transported to a production plant and stored. When production begins, the materials are heated and mixed together in large mixing drums. The amount of each material that is added to the mix is carefully controlled so that the job mix formula, a “recipe” for the asphalt concrete that is based on volumetric properties, is met. If the job mix formula is not met, the quality of the asphalt concrete will suffer.

After mixing, the asphalt must be kept at a high temperature so that it does not cool and harden. To keep the mix hot, it is placed in a heated storage silo for a couple of hours until trucks arrive to transport the material to a jobsite. Once the hot mix has arrived at a job site, it is placed into a paving machine. This machine places a mat of hot asphalt concrete down along the road section. After the mat has been laid, rolling equipment will make multiple passes over the hot mix to compact the asphalt concrete to a desired density. After the pavement has fully cooled, it is ready for traffic.

The high temperatures asphalt binder is exposed to in storage will age and embrittle the material through oxidation and volatilization. Asphalt binder will continue to age throughout its lifetime, but most of the aging occurs during production, because the elevated temperatures accelerate the process. Previous research conducted at UNH has shown that as silo storage time increases (more time spent at elevated temperatures), asphalt concrete specimens became stiffer and more brittle. All things being equal, brittle mixes tend to perform poorly in cold climates like New Hampshire because they cannot dissipate traffic or environmental induced stresses and are much more susceptible to cracking. Cracking is a major problem for pavements, allowing water a direct path to penetrate the pavement structure, which will soften and weaken the underlying layers. This process significantly weakens the entire pavement structure, which will lead to further cracking and durability issues down the road. If the damage becomes severe, expensive maintenance and repair is required.

Here is an example of an asphalt pavement that has experienced thermal cracking. The cracks typically occur in a transverse direction and are spaced at regular intervals.

The main objective of this research project was to evaluate how silo storage time impacts asphalt pavement’s susceptibility to low temperature thermal cracking. Thermal cracking, which is a prevalent distress in pavements in cold weather climates such as New England, occurs when an existing pavement section experiences a cooling event (nightfall, sudden weather change, etc.) As asphalt concrete cools the material tries to contract, causing tensile stresses to develop in the pavement because it is restrained by the soil underneath. If these tensile stresses become large enough to exceed the strength of the asphalt concrete, a crack will form. As the pavement experiences more cooling cycles over a period of months and years, this initial crack will grow in both length and width, eventually growing to the full width of the roadway.

A secondary goal of the project was to compare how two typical asphalt specimen production methods (production plant made and lab made) differ in terms of low temperature thermal cracking susceptibility. Currently, both plant and lab specimen production methods are considered equally valid for testing, however both production methods experience different temperature and aging conditions. Understanding how these production methods impact thermal cracking performance will give researchers a better understanding of their testing data.

How Can You Determine if Asphalt will Crack?

Although there are many asphalt testing procedures available to determine cracking performance, I chose the DCT (Disk-Shaped Compact Tension) test. The DCT test, developed from a common metal fracture test, simulates the tensile stresses a pavement layer experiences during a cooling event. The DCT test has been shown to effectively distinguish good performing mixes from poor performing mixes in cold climates. DCT results have also correlated well with field results, making the test an excellent choice for this project.

To evaluate how silo storage time impacts pavement performance, I tested eight different mixes. All mixes were made from the exact same materials, but each spent a different amount of time in silo storage (0 hours, 2.5 hours, 5 hours, and 7.5 hours). These storage times were chosen as they represent typical ranges asphalt mix could be exposed to during production. The eight mixes also varied by the fabrication method (plant made or lab made).

DCT testing fixture used at UNH. The vertical bars pull on the specimen, generating tensile forces at the end of the notch cut into the asphalt concrete.

Four of these mixes were delivered to the asphalt materials lab at UNH in metal buckets by Callanan Industries, an asphalt plant in New York. The buckets contained what is typically called "loose mix." Loose mix is asphalt that was placed into a bucket directly from a storage silo, never compacted or molded. The loose mix is reheated with ovens in the lab to make testing specimens. Since these specimens are produced in a lab, they are called lab produced specimens.

The other four mixes were delivered as prepared specimens from the same plant in New York. These specimens are known as "gyratories" within the asphalt field. Gyratories are six inch tall compacted asphalt cylinders that are the basis for most laboratory asphalt tests. The gyratories for this research were produced with the same materials as the previously mentioned loose mix. Since these specimens were prepared and compacted at an asphalt plant, they are known as plant produced specimens.

The key difference between the lab produced and plant produced asphalt specimens is that the lab produced specimens experience additional aging when they are reheated in the lab. Typically, this will stiffen and embrittle the asphalt compared to plant produced mixes which do not experience the additional aging. Three specimens were tested from each of these eight mixes, totaling twenty-four total specimens to test. The testing results were averaged between the three specimens for data analysis.

The Ups and Downs of Research

The first accomplishment of the research project involved setting up the DCT test on our existing testing frame so that it is run according to specifications. This work included installing and testing specimen preparation equipment, calibrating measuring devices, tuning the testing frame for the DCT test, and finally running pilot tests to ensure everything was working correctly and reliably.

The first challenge was fabricating the DCT fixtures. When making the original timetable, I had anticipated that the fixture parts were going to be ordered from a company who sells these parts, so I allowed just one week to order and setup the fixture. However, these parts had to be fabricated at a local machine shop, which took much longer than I had anticipated (almost six weeks). Although this did not cause huge setbacks for the project overall, the delay caused me stress. The best way to deal with this was to get as many of the other tasks done so that I could immediately move on once the fixtures were ready.

The whole process of setting up the DCT test took almost two and a half months, leading me to extend the research deadline an extra month. I initially believed the testing would take four to five weeks, but because most of the summer was spent preparing the testing equipment, it seemed that some of the testing itself would have to be performed during the school year. In my mind, this was a huge concern, knowing that I would not have enough time to sit down for four or five hours of testing during the semester. After a computer hard drive failure delayed the whole project another week or two, I went into full panic mode and began considering modifying or dropping parts of the project all together. Luckily, none of my “doom and gloom” predictions came true. Once all of the equipment had been properly setup, the testing went smoothly. I was finished a day before the deadline, and before the semester began. In the end, I became much better at dealing with the many setbacks involved with setting up a research project.

Finding the Relationship between Storage Time and Crack Susceptibility

Once I collected the testing data, I analyzed it in Microsoft Excel® and MATLAB®. Three key results were obtained. The first was fracture energy. Fracture energy is a parameter that measures how much energy is required to completely fracture the specimen. Fracture energy is useful to measure because it correlates well to how much thermal cracking a pavement section will experience. High fracture energy indicates an asphalt mix that is less susceptible to thermal cracking, while a low fracture energy indicates the opposite. The trend that I expected to see was that as silo storage time increases, the fracture energy would decrease. This is because aging occurs when the asphalt is at elevated temperatures in the silos. Typically, the aging process embrittles the asphalt mix, making the material stiffer and more prone to cracking. Interestingly, the results did not reflect this; the observed trend was the exact opposite. In general, the fracture energy increased with an increase in silo storage time. Although there is no obvious answer to explain this, it seems that any increase in brittleness is being outweighed by an increase in the absolute strength of the material with storage time.

Another parameter I measured was the peak load. The peak load represents the largest amount of force that the specimen could withstand, or the ultimate strength of the material. After the specimen experienced the peak load, a small crack formed on the specimen. The results show a clear relationship between silo storage time and peak load. As silo storage time increased, the peak load also increased. This makes sense considering that as this strength increases, it takes more energy to break the material, as shown in the fracture energy results.

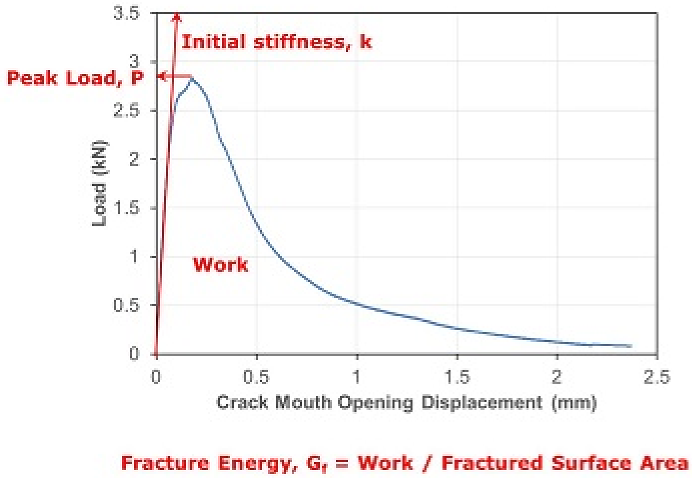

Fig. 1: A typical load vs. crack mouth displacement curve from a DCT test. Fracture energy is calculated by finding the area under the curve, peak load is determined by the largest force value during the test, and the stiffening slope is calculated by measuring the tangent slope of the initial rise on the plot.

The last parameter I measured was the slope of the stiffening curve. After each test, a force versus crack mouth displacement (how much wider the crack/notch became when the specimen was pulled on) plot was constructed. The initial points of this plot, which is called the stiffening curve, are usually steep and linear. Measuring the slope of the stiffening curve gives an indication as to the stiffness of the material. In general, the results showed an increase in slope (or stiffness) with additional storage time. This agrees with previous findings from the silo storage project conducted at UNH. This result seems to contradict the fracture energy results of my project, however, where additional storage time increased the fracture energy of the material. Therefore it is important to note that stiffness does not necessarily mean that the material will be weaker. In fact, all an increase in stiffness means is that the material will deform less under load.

The other major goal of my project was to investigate the differences between lab produced and plant produced specimens in terms of their thermal cracking susceptibility. The results from the DCT test consistently showed that the lab produced specimens were more susceptible to cracking (had lower fracture energies) than the plant produced specimens. This makes sense, considering that producing lab specimens requires two and a half extra hours of aging, which makes the material more brittle. Interestingly, this observation also contradicts my other results which showed that increased storage time and aging increased the fracture energy of the material. While there is no immediate explanation for this, one could assume that the different aging methods have different effects on the asphalt specimens. To isolate the potential differences between the two production methods, further testing is needed.

Going Forward

This research is important to the asphalt industry because very little is known on how silo storage time impacts pavement performance. Ideally, new information will allow asphalt producers and state DOTs to modify pavement mixtures and/or construction techniques to accommodate the changes asphalt experiences during silo storage. One example would be that the asphalt mix design could be modified so that there is either more binder or a softer binder. Both of these modifications would likely make the asphalt much more flexible and crack resistant. These changes, which could be done without any significant challenge, will provide pavements that will last longer and perform better than current pavement designs.

This project was important for my personal and career goals as I continue my education into graduate school. Considering most master's programs consist of research and thesis work, the experience I gained from this project will be invaluable in pursuing that goal. Being able to draw on the experience I gained from creating a proposal, setting up the project, conducting research, data analysis, writing the final report, and presenting the project will be extremely useful going forward.

Going into the project, I had certain expectations of what was ahead. Looking back, very few of those expectations actually occurred. Throughout the entire project new obstacles were always occurring at seemingly the worst times. Although frustrating, I now realize that all of these obstacles are an inevitable part of the research process. Because of my experiences over the summer, I have gained a whole new appreciation for the research process and those who conduct it. I now realize how much work goes into the great findings that come about because of research. This experience not only enlightened me, but it also piqued my interest in conducting research. Before this project, I wasn't sure if I would want to continue on to a graduate degree because of the research portion. Now I am genuinely interested in continuing on to graduate school, and possibly a career in a research based field.

First, I want to thank Mr. Dana Hamel and the UNH Parent's Association, who generously contributed the funding for this project through a Summer Undergraduate Research Fellowship. Their kind and selfless contribution made this project, and many others, possible. I also want to extend thanks to the Hamel Center for Undergraduate Research staff for all of the help they gave me during the research project. I would like to extend my deepest gratitude to Dr. Jo Daniel and Dr. Eshan Dave who served as my faculty mentors during the research. Both helped me immensely through every aspect of the research, as well as my entire undergraduate career. I would not be where I am today without their guidance.

Author and Mentor Bios

Christopher DeCarlo is a civil engineering major from Chester, New Hampshire. He will graduate in spring 2016 with a bachelor's of science, and plans to go to graduate school. On the advice of his advisor, Christopher sought a Summer Undergraduate Research Fellowship (SURF) grant to pursue this project through the Hamel Center for Undergraduate Research. He discovered the possibility of writing an article after the project was complete, and felt *Inquiry* would be a good experience. He admits, "I rarely get to write anything other than reports, so writing a somewhat open-ended article seemed interesting." Christopher learned a lot from his experience, both about asphalt, and about research in general. Although Christopher's research journey was also a bit rocky, he learned to roll with the punches. "The research process itself is nowhere near as predictable as I thought," he explains. "I couldn't have imagined all of the twists and turns this project took... As frustrating as they were, I'm glad that they did happen because that was the best experience of the whole project." In the end, Christopher pulled through confusion to success, describing his results as giving him "one of the greatest feelings of accomplishment I've ever had." In the future, Christopher is leaving his options open, but he is interested in agency work, like the New Hampshire Department of Transportation, or the Federal Highway Administration. He feels that his work on this project has directly contributed to these goals.

Dr. **Jo Sias Daniel** is a professor in the department of civil and environmental engineering at the University of New Hampshire, and has been with the university for almost fifteen years. Dr. Daniel specializes in rheological and damage characterization of asphalt mixtures. She became involved in Chris' project because he had been working as an undergraduate research assistant helping graduate students, and had expressed interest in an independent undertaking. Pleased with his persistence in overcoming difficulties, Dr. Daniel joked, "I was impressed with Chris' tenacity (pun intended) in getting the testing setup developed and running." Although Dr. Daniel has mentored many undergraduates, Chris is her first *Inquiry* author. She believes writing for broader audiences is definitely beneficial for her students.

Dr. **Eshan V. Dave** is an assistant professor in the department of civil and environmental engineering at the University of New Hampshire, and has been with the department for a year. Dr. Dave specializes in engineering materials and transportation engineering. He is a veteran mentor from his previous appointment at the University of Minnesota Duluth, but Chris is his first *Inquiry* author. The experience was positive; Dr. Dave notes, " As a researcher, [Chris] truly made a positive impression on me... the experience really allowed me to work closely with a student... I believe I learned to be a better mentor and supervisor." It's likely Dr. Dave will continue to mentor *Inquiry* authors in the future, as he "firmly believe[s] that learning to write in journals such as *Inquiry* is very useful to students in engineering."

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