TechBrief

The Asphalt Pavement Technology Program is an integrated national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry and academia, the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement suggestions, methods, procedures and other tools for use in asphalt pavement materials selection, mixture design, testing, construction and quality control.

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Overcoming Obstacles to Achieving Density

This Technical Brief summarizes techniques used to overcome obstacles to achieving increased density on individual State projects associated with the FHWA Enhancing Durability of Asphalt Pavements Through Increased In-Place Density Demonstration Project.

Introduction

This is the third of four planned Technical Briefs on ***Enhancing Durability of Asphalt Pavements Through Increased In-Place Density*** associated with the Federal Highway Administration (FHWA) Accelerated Implementation and Deployment of Pavement Technologies (AID-PT) program. The AID-PT program advances best practices and technologies for constructing and maintaining high-quality, long-lasting pavements in accordance with six goals established by Congress (1). The overall objective of the demonstration project was to show that additional density could be obtained through improved techniques.

This set of Tech Briefs focuses on the importance of mat and joint density, techniques and tools that have been demonstrated to help improve density, examples of specifications, and overcoming obstacles to achieving density. The information used to develop them was obtained through review of the technical literature identified in the references in this document, a series of workshops and support of 29 field demonstration projects performed by State Departments of Transportation (DOTs). This is the third in the planned series of the four Technical Briefs that are organized as follows:

1. Density Demonstration Projects and Related Specifications
2. Techniques and Tools for Improving Density
3. Overcoming Obstacles to Achieving Density
4. Improving Longitudinal Joint Performance

Although several factors can influence the performance of an asphalt pavement, one of the most important factors is in-place density (2). A small in-place density increase can potentially lead to a significant increase in the service life of asphalt pavements. According to the studies reviewed in the literature, a 1 percent increase in density (percent of G_{mm}) was estimated to improve the fatigue performance of asphalt pavements between 8 and 44 percent and improve rutting resistance by 7 to 66 percent (3, 4). In addition, based on field data, a 1 percent increase in density would conservatively extend the asphalt pavement service life by 10 percent.

Recognizing the importance of in-place density in building cost effective asphalt pavements, FHWA initiated the Demonstration Project for "Enhanced Durability of Asphalt Pavements through Increased In-place Pavement Density" (4, 5, 6, 7). The objective of this demonstration project was to support DOTs in their evaluation of their existing density requirements for acceptance. Twenty-six DOTs participated with 121 experimental sections constructed, comprised of 35 control sections and 86 test sections.

There were many variables including mixture type, construction equipment, and procedures between States and within States, making it very difficult to compare the density results between various pavement sections. The number of variables that were intentionally changed within a State was much less than the number of changes between States. This was expected, as it was a demonstration project and not a formal experiment. As a demonstration project, each State (the contractor and agency) was empowered to focus on changes to improve density that it thought would be most beneficial for its situation. So, it was much easier to compare the changes made within a State to show the effect of these changes on in- place density. This Tech Brief highlights what contractors and DOTs did to overcome obstacles to achieve density. Additional details on the demonstration projects can be found in References 4 through 7.

While constructing the experimental sections throughout the three phases of the demonstration project, there were situations that presented obstacles for increasing in-place density. In most cases, these obstacles were overcome.

There are several practices to overcome obstacles to obtain increased density documented in the literature (2, 8, 9). A summary of these include:

- Understanding factors affecting compaction such as material properties (aggregates, asphalt binder and mixture properties), environmental variables (layer thickness, temperature, wind velocity, solar flux, and time available for compaction), and types of rollers,
- Determining a roller pattern and identifying the tender zone if it exists, measuring density while using applying the roller pattern, and adjusting the roller patter to compact stiff and/or tender mixture as they occur, and
- Addressing mat problems such as surface waves, tearing, nonuniform texture, screed marks, screed responsiveness, surface shadows, poor compaction, joint problems, checking, shoving, bleeding, roller marks, and segregation.

The information presented here is intended to document some of the practices encountered on FHWA's density demonstration project and to supplement and expand upon the published literature.

Obstacles to Achieving Higher In-Place Density

The following are seven primary obstacles to achieving higher in-place density observed during construction of the experimental sections throughout the three phases of the demonstration project. Other obstacles not observed during the demonstration project could arise. The primary obstacles encountered were:

- Stiff Mixture.
- Tender Mixture.
- Aggregate Degradation.
- Weak Subgrade and/or Base.
- Break Point Density Control.
- Smoothness.
- "Roll Until Meets" Philosophy.

A description of each obstacle follows. Examples of techniques used to minimize impacts of or eliminate the obstacles are also described.

Stiff Mixture

Some asphalt mixtures are very stiff, posing challenges to obtaining higher in-place density. Several factors influence mixture stiffness. Examples include asphalt binder stiffness, aggregate properties and gradation, recycled materials, mixture temperature and ambient conditions. Figure 1 illustrates the sensitivity of asphalt mixture stiffness (modulus) to temperature for an array of different mixture types (10).

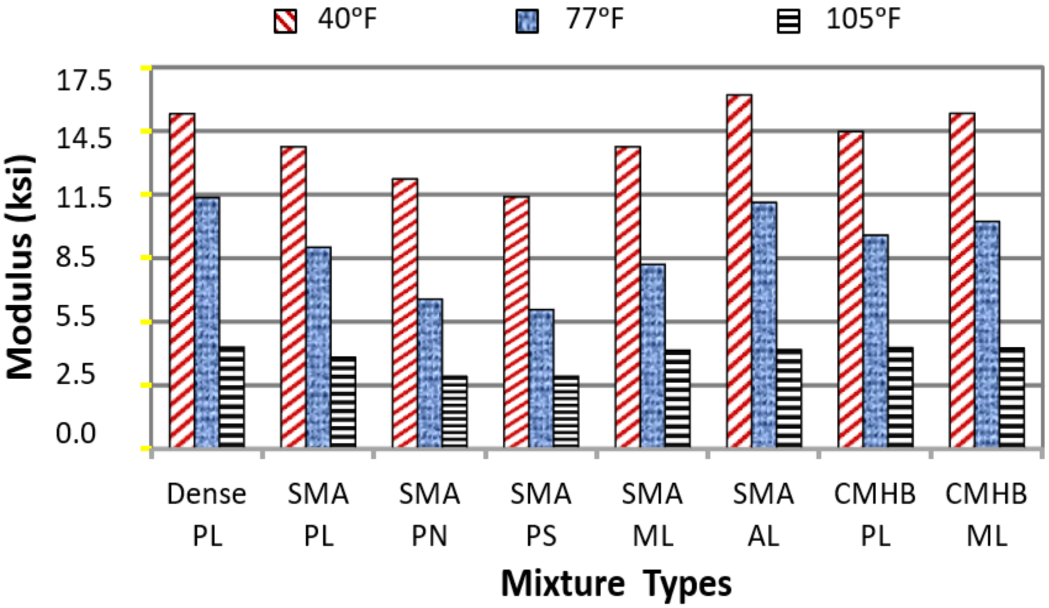

Figure 1. Effect of Temperature on Mixture Stiffness (10).

One of the most important strategies with stiff mixtures is to compact them while they are hottest and have the lowest stiffness. Ten demonstration projects used breakdown rollers in echelon. This strategy allows for twice the number of passes in the same time, as compared to a conventional roller pattern that has one breakdown roller. With breakdown rollers in echelon, more passes are applied while the asphalt mixture is hottest. This is also an important benefit when compacting thin lifts and late season compaction when the mat cools very quickly. Figure 2, generated with Multicool Software output data, illustrates how rapidly mat temperature drops under typical conditions, for different lift thicknesses (11). The free Multicool tool can be used to determine the amount of time available to achieve compaction. The output can be used to help make decisions about paving speed, roller types and number of rollers. In Figure 2, 1.5 and 3.0 inch lift thicknesses are illustrated. The 1.5 inch lift cools from 300°F to 200°F in just 9 minutes with ambient and base mixture temperatures of 40°F. The 3.0 inch lift cools from 300°F to 200°F in 28 minutes under the same conditions.

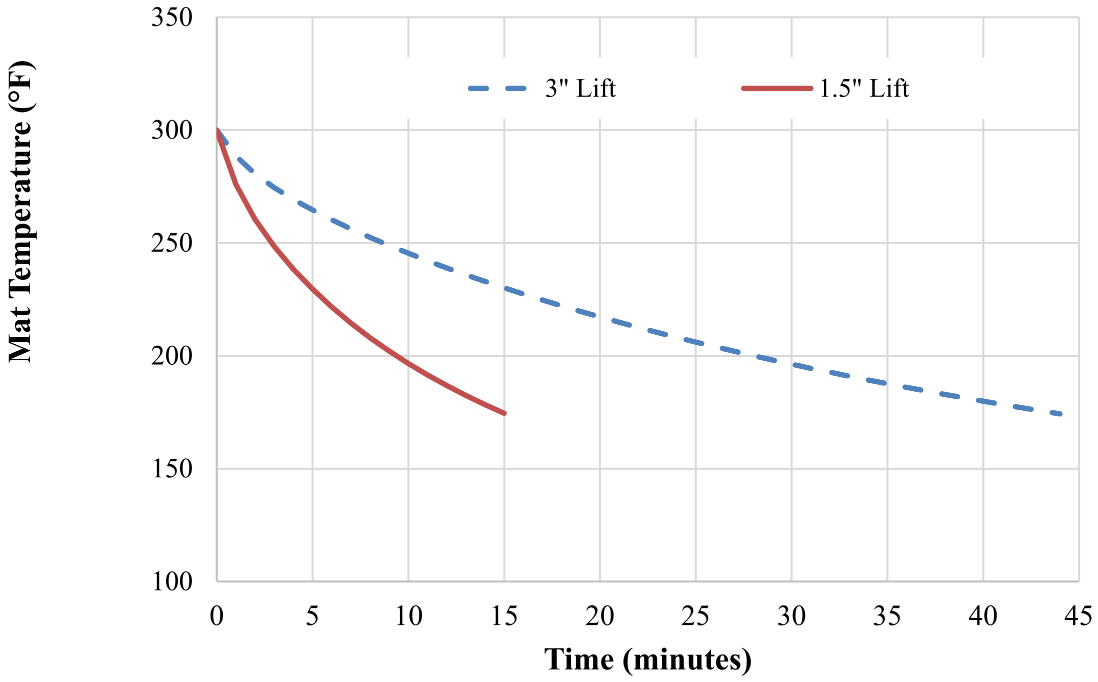

Figure 2. Multicool Mixture Cooling Rate Example.

Three demonstration projects also used intermediate pneumatic tire rollers in echelon. Applying the most compactive effort while the asphalt mixtures were hot was a very effective strategy. A few suggestions to obtaining density on a stiff mixture include:

- Tight roller patterns were effective on two of the demonstration projects. Keeping rollers at consistent spacing and the breakdown roller near the paver helped achieve density more quickly. It also reduced the standard deviation of the density results. Conversely, it is particularly important to avoid the "lazy" roller pattern in which the rollers have large spaces between them and are far behind the paver.
- Balancing the paver speed with the speed of the rolling is important. If a paver speed is too fast, it can "outrun" the rollers and make achieving density more challenging. Often a consistent paver speed which is balanced with the available rollers can have the same production as using a fast paver speed and a lot of stopping and starting. Figure 3 is a reminder that, to have consistent paving and compaction speed, the entire operation from plant production to final compaction should be balanced. A balanced operation also leads to improved ride quality because it reduces stops and starts.
- It is generally desirable to obtain all but approximately 2 percent of the target density needed by completion of the breakdown rolling. If this is not being achieved, then this would be a time for a contractor to review the common practices such as temperature, speed, using breakdown rollers in the echelon position, etc.

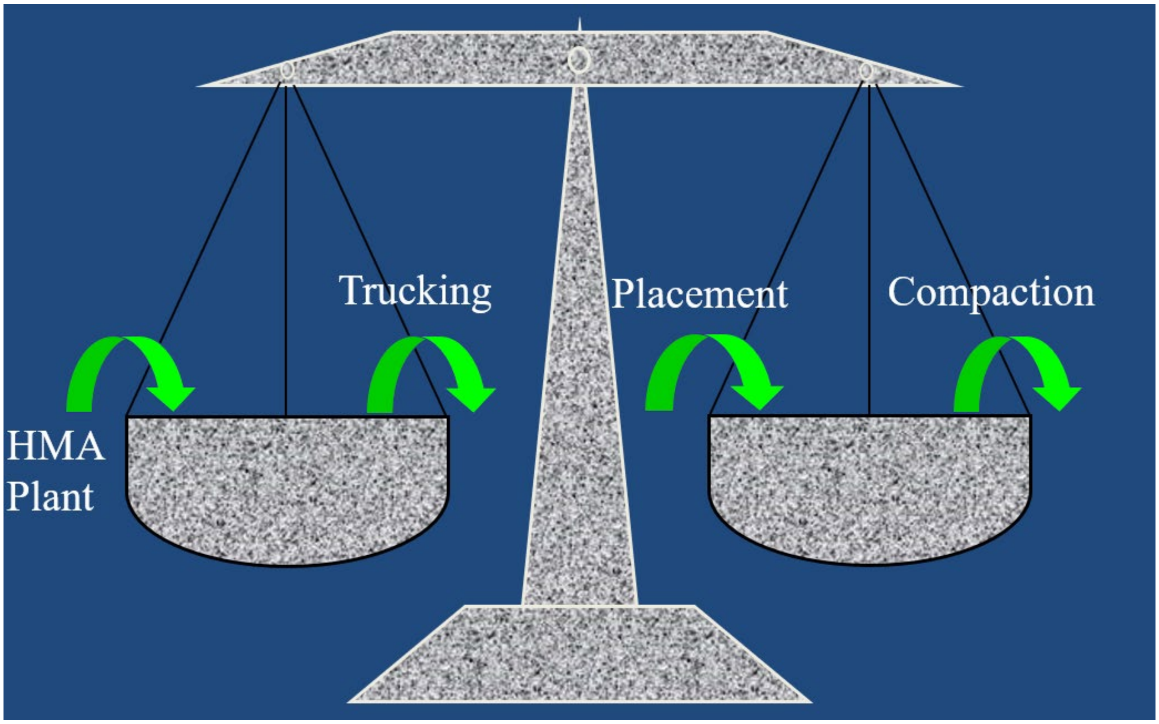

Figure 3. Balanced Operation Considerations.

Tender Mixture

Some asphalt mixture moves a lot under the rollers. The mixture may form a large bow wave in front of the roller and/or move laterally. This is sometimes noticeable only with the first pass of a steel drum breakdown roller. Lateral movement is considered excessive if it continues after the initial pass. This was experienced on one demonstration project. These asphalt mixtures are difficult to compact and often referred to as "tender mixture." Tender mixture may be created by properties of the mixture design or additional fluids. In this demonstration project, it was believed to be primarily from additional fluids. The fluids could be from moisture within the aggregates or reclaimed materials that was not removed by the asphalt plant. The additional fluids could also be from additives (e.g., anti-stripping additives, warm mixture asphalt additives, etc). Tender mixture may also be a result of a soft binder. Some binders have very low, low-temperature grades or modifiers that are used for the binder to meet State-DOT-specified performance grades.

The "tender zone" occurs through a specific temperature range for any given mixture. Tender behavior (pushing and shoving under the roller) occurs in the tender zone and the mixture behaves normally (more stable) at temperatures above and below the tender zone. The upper and lower temperature limits of the tender zone are commonly identified by observation in the field and measuring temperature of the mat while observing mixture behavior under the action of steel drum rollers. A typical example of a tender zone may be from 230°F down to 190°F. Echelon rolling can be used to achieve density before the mixture cools to 230°F (in this example). Alternatively, where density is not achieved before the mixture temperature reaches the upper limit of the tender zone, further compaction is carried out after the mixture cools below the lower limit (190°F in this example). Depending on job-site conditions, this approach may be nearly impossible to achieve and echelon rolling may be necessary. It has also been found that the diameter of the roller's drum can have an impact. The larger the diameter of the drum, the less impact the roller has on creating the bow wave. A larger diameter drum has a lower angle of attack.

In any case, the cause of a tender mixture should be identified and addressed. When dealing with tender mixture from additional fluids (i.e., moisture), it is important to make adjustments at the plant. The moisture needs to be removed in the drying process and/or the additives need to be accounted for as part of the mixture design.

Time typically heals these issues, and the pavement can experience normal performance once the asphalt mat "sets," "cures," or "dries." If the mat does not do this in a reasonable time, then the mat can be removed with a skid steer or front-end loader. A question often arises when tender mixtures are encountered, which is to ask about the appropriateness of rolling to obtain additional density tomorrow. Although it is possible, it is not desirable. It is important to identify the cause of the tenderness and make the appropriate adjustments at the plant (e.g., removing the moisture during the drying process in this example.)

Aggregate Degradation

There were aggregates that degraded under compaction on two of the demonstration projects. During the control section, the normal compaction process was followed. Two double drum vibratory rollers were used in echelon in the static mode. The density in these sections was lower than the density observed with many of the other DOT specifications (6). As part of the test section, a pneumatic roller was added. The density was increased such that the density in the test section averaged over 94.0 percent. Pneumatic rollers can be very effective when compacting asphalt mixtures with aggregates that degrade. Further, pneumatic rollers were used on three demonstration projects in the intermediate position in echelon. Not only could this strategy assist with preventing degradation of aggregate, it was also observed that there was a lower standard deviation of density results. Pneumatic rollers have also been known to provide more uniform compaction through the depth of the asphalt layer.

Another demonstration project had some lessons learned related to aggregate degradation. The maximum in-place density of the mat achieved for Section 1 at Location A was 93.0 percent after 20 passes applied by the breakdown and intermediate rollers. The compaction process stopped when some aggregate degradation was observed in the mat. The roller's amplitude, frequency, and speed were not coordinated, and it was apparent that something was wrong. Section 1 was not considered positive as the contractor was not able to "break" the density (i.e., a peak density was not realized) of the mat. However, several lessons can be learned from this experiment, and they are discussed below with suggestions for future improvement.

- Mixture design. The mixture design used in Section 1 may need to be examined. A mixture design with a high recycled content (from recycled asphalt pavement—RAP—and recycled asphalt shingles—RAS), such as the one used in Section 1, may need more virgin asphalt than the optimum binder content determined based on the volumetric parameters alone (i.e., AASHTO M323). The high recycled content made the mixture very stiff and more difficult to achieve a higher in-place density.
- Compacting when it is hot. An effective way to achieve a higher density and prevent aggregate degradation is to compact the mat when it is hot. The temperature of the mat behind the paver could have been higher, especially for an asphalt mixture with a high recycled content. One of the methods to compact the mixture when it is hot is to have two breakdown rollers operating in echelon. Twice the number of passes can be made in a given amount of time.
- Importance of vibration amplitude. The high amplitude used for compaction may have been too high. A lower amplitude would have reduced aggregate degradation. However, with the stiff mixture (low temperatures and high recycle), high amplitude may have been the only option to achieve

higher density. To reduce aggregate degradation, a lower amplitude with higher frequency and higher temperatures would have been better.

- Use of pneumatic roller. A pneumatic roller has successfully been used as an intermediate roller in other demonstration projects to increase in-place density without breaking aggregates in the mat. On one demonstration project, with a limestone aggregate with a history of degradation during compaction, a single pass was made with a typical steel double drum breakdown roller operated in the static mode. Then echelon compaction with pneumatic rollers was used to obtain all but 1.0 percent density of the DOT specified density. This technique led to 93.8 percent average density and a standard deviation of less than 1.0 with no visible broken aggregates. The echelon pneumatic rolling is illustrated in Figure 4.
- Use of WMA at lower temperatures made the mat more challenging to compact. Although WMA can allow for lowered temperatures, this generally applies for WMA with virgin mixture. This particular mixture in Section 1 had a high recycled content. The combination of lower temperatures (even with WMA) and higher recycled material contents still resulted in the mixture being very stiff and difficult to compact. This scenario could result in a lower maximum in-place density and aggregate degradation.

Image: University of Nevada Reno

Figure 4. Use of Tandem Pneumatic Rollers for Achieving Density without Broken Aggregates.

Weak Subgrade and/or Base

Often the asphalt pavement is paved directly on soil subgrade or aggregate base course. In many of these cases, the subgrade and base are weak or soft (particularly when compared to the stiffness of the asphalt mat) and make it challenging to obtain density in the asphalt mixture being placed.

One State participating in the demonstration project uses a lower density requirement in the lowest lift for these cases, recognizing in advance that there will be an obstacle to achieving density. In high traffic applications, the lower limit of density is decreased by 1.0%, and in low traffic applications, the lower limit is decreased by 2.0%.

Prior to a State DOT lowering the density requirement, options should be considered. One option is to see that the subgrade or base is properly compacted by using an appropriate density specification. Historically, proof rolling is also an option to check for soft spots. More recently, intelligent compaction has shown to be an effective tool to identify areas of weak base support by pre-mapping prior to paving. It is important to determine the cause of the weak subgrade or base and corrected it for long-life pavements.

A second option can be employed as part of the mixture design. Since the lowest lift is almost always a fatigue resistant layer, it could be designed at a higher asphalt content. A higher asphalt content will help the fatigue resistant layer meet its intended function and also make it more compactible against a soft or weak subgrade or base. In these cases, a DOT could create special mixture design criteria for the purpose of increasing the asphalt content. A fatigue resistant pavement layer will be more effective with a higher asphalt content and higher in-place density.

Break Point Density Control

On some demonstration projects, plots of the relationship between number of roller passes and density were developed, commonly on a test strip or at the start of the project. The number of passes at which the density peaked was identified as the “Break Point” density and “Break Point” number of passes.

On three demonstration projects, a strict emphasis was placed on the Break Point number of passes being the number of passes used during construction. The density curve and break point provide valuable information, but there needs to be flexibility when conditions vary during a project. It was noted that these same three projects had some of the lowest densities in the control sections of the entire demonstration project.

Conversely, strict adherence to the density curve and break point can be misleading in identification of the number of roller passes needed. There are many factors that change with time: temperature, moisture, type of roller, etc. Sometimes a pause may be necessary to start increasing density again. Sometimes aggregates reorient and decrease density prior to increasing density again. This could be considered a density that could be a “false summit.” This has also been observed with many asphalt mixtures, including some polymer modified mixtures. The density curves do not account for rollers in echelon and could even encourage “lazy” roller patterns. The density curve and break point are a useful tool, but they should not be used so strictly as to hinder gaining additional density.

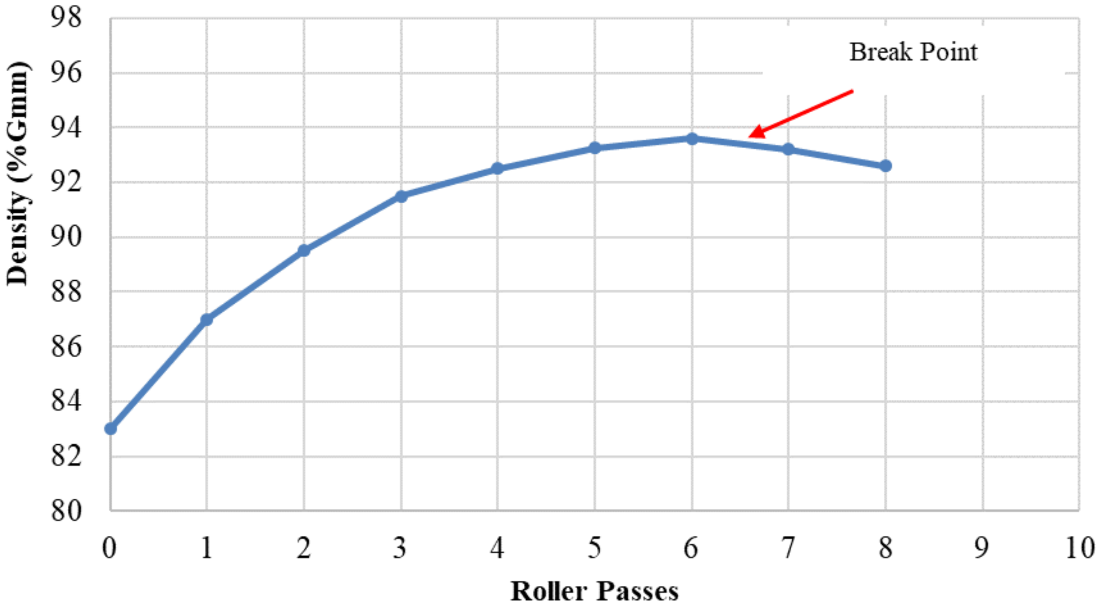

Figure 5. Density versus Roller Passes Curve.

As another point, a contractor's most focused effort is often provided during the construction of the test strip. When actual production for the project begins, things can change. Contractors may speed up their paving operation and go faster than they did on the test strip, which can negatively impact the ability to obtain density. The results of the roller pattern study are then no longer applicable. This further emphasizes the importance of flexibility.

Smoothness

In some cases, it has been reported that excessive rolling of the asphalt mat creates issues with smoothness. Throughout the course of this demonstration project, that issue did not occur but was raised as a concern. It should be noted that the biggest influence on smoothness under the contractor's control is related to the paver operation and mixture delivery. The biggest influence to obtain smoothness under the agency's control is the number of lifts and thickness of each lift.

Rollers play a minor role in impacting smoothness. If for some reason the roller is creating an issue with smoothness, it can be fixed by matching the amplitude, frequency and speed. This is often accomplished by slowing down the roller and making sure there are 10 to 12 (sometimes even up to 16) impacts per foot. If fewer impacts per foot are applied, usually due to increasing roller speed, it can become visible on the mat, as shown in Figure 6. This is a clear indication that a vibratory roller frequency and operating speed should be reviewed to increase the drum impacts per foot. However, it is recognized that slowing down the roller can be challenging if the paver speed is fast. As another consideration, by going slower with the roller there may need to be fewer passes by the roller, making it easier to keep up with the paver.

The type of roller can impact smoothness. Oscillation was a helpful tool for creating a smoother finish. Some demonstration projects successfully used oscillatory rollers. The oscillatory roller can be used when the mixture gets below the temperature in which vibration can't be used and create a much smoother finish.

Image: Adam Hand

Figure 6. Visible Drum Impacts from Excess Roller Speed.

Throughout the demonstration project, it was observed that roller pattern techniques are a key to smooth pavements as well. Operators stopped at the end of their passes on an angle, not straight. They also did not stop in the same location. Instead, they rolled through their last stopped location at the end of their pass. Further, operators neither shut off vibratory mode too soon nor start them back up too late. The roller only went as far as a length and a half of the machine or as long as the rear drum goes past where the front drum stopped vibrating.

"Roll Until Meets" Philosophy

As a finding in the FHWA's density demonstration project, no extraordinary compactive effort was generally needed to obtain increased density. States and contractors worked together to identify numerous methodologies to do this. When a DOT writes a specification, the contractor's goal is to meet the specification and be the lowest bidder. Thus, the contractor strives to provide the DOT what is required in the specification as efficiently as possible. This often leads to a philosophy toward the compaction process of "rolling it until it meets."

There is nothing intrinsically wrong with this philosophy. However, when a DOT has low density-specification requirements, the contractor may bid the project with fewer rollers and fewer passes. This was observed most notably on one of the demonstration projects. The specification was a lot average with a lower limit of 91.0 percent. The contractor met the specification with only one, double-drum vibratory roller making seven passes. A one percent higher density was achieved with only two more passes in the test section. This was the fewest number of rollers and fewest number of passes in this entire demonstration project. By setting reasonable limits, DOTs can encourage contractors to respond with innovative approaches to obtain the higher density.

Summary

There are sometimes challenges when trying to increase in-place density. When DOTs embrace the idea to increase the density requirements in their specifications, contractors and agencies often have a learning curve that can identify such challenges. There are examples of strategies, presented in this Technical Brief, to overcome the challenges of obtaining increased in-place density. The in-place density challenges may be overcome with strategies that can involve partnering, time, and education.

This third Technical Brief in the series of four on ***Enhancing Durability of Asphalt Pavements Through Increased In-Place Density*** presented an effort as part of a larger project to improve in-place density achievable for asphalt pavements across the country. The other three Technical Briefs describe the density demonstration projects and related specifications, techniques and tools for achieving density, and improving longitudinal joint density.

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