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HOT MIX ASPHALT TENDER ZONE

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DISCLAIMER

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INTRODUCTION

Approximately 500 million tons of hot mix asphalt (HMA) are placed in the United States each year. With this large quantity of HMA, it is expected that some construction problems will occur from time to time. The jobs that experience construction problems are often widely publicized, while other jobs that don't experience problems are usually never discussed during the project nor after the project is completed. This does not minimize the importance of recognizing existing problems and solving these problems during the construction process, but it does indicate the need to keep construction problems in perspective.

One problem that has been observed for years, on a small percentage of projects is tenderness of some mixtures during compaction. Tender mixtures are not stable under the roller and tend to move laterally when rolled. This lateral movement sometimes results in hair-line cracks, often referred to as checking. In the past, most tender mixes were attributed to excessive temperatures and/or over sanded mixes. There are many other possible reasons for the tender mixes, but these two causes of tender mixes appeared to be mentioned most often.

In the early to mid 1990s, Superpave mixes began to be used in the U.S. For the most part, these mixes have been coarse-graded (below the restricted zone) mixes with relatively high coarse aggregate content. Experience has shown that when these mixes are tender, they act similar to tender mixes that were encountered in the past. It is difficult to quantify the number of projects that do experience some tenderness, but based on two surveys by NAPA and conversations with many contractors, it appears that approximately 40 percent of coarse-graded Superpave mixes experience some tenderness. It has also been observed that this tenderness does not occur immediately when rolling begins, but instead, it begins a short time afterwards when the mix temperature is reduced. Most information indicates that for tender mixes the tenderness begins once the surface temperature of the mat drops to approximately 240°F and tenderness continues until the temperature drops to about 180-190°F and on some jobs as low as 150°F. Of course, these temperatures are approximate ranges and each tender mix will behave differently.

This temperature range (150-240°F) in which the mix is tender has been referred to as the tender zone. The tender mixes often do not act tender when the mix temperature is above or below the range for the tender zone. However, approximately 40 percent of the mixes with a temperature within the tender zone show some amount of tenderness problems when being compacted. When tenderness occurs, the surface of the HMA may move laterally up to nearly one foot in extreme cases when being rolled. In other words, a mat that is placed 12 feet wide may end up being close to 13 ft. wide in extreme cases after being compacted. Normally for tender mixes, the mat will move approximately 2-4 inches when being rolled.

The objective of this paper is to provide guidance on handling of mixes that may be tender during compaction. Information is provided for techniques to reduce mix tenderness and recommendations are made for preferred compaction techniques for mixes that continue to act tender.

FHWA-NAPA PARTNERSHIP

As a result of reported tenderness problems, the Federal Highway Administration (FHWA) and the National Asphalt Pavement Association (NAPA) held a jointly sponsored meeting in June 1998 to discuss tender mixes. The attendees at this meeting included state DOTs, FHWA, and Industry representatives. There was a lot of discussion at the meeting about causes and cures of the tender mix problem. Several individuals had some experience concerning tender mixes. After the meeting, several other individuals were contacted and interviewed about tender mixes. As more experience has been gained, it appears that most contractors are able to work around the tender mix problem. However, tender mixes continue to occur and create difficulties on some construction projects. This document has been prepared as a direct result of FHWA and NAPA concerns about continuing problems with tender mixes.

DESCRIPTION OF TENDER MIX PROBLEM

As stated earlier, tender mixes during construction have been a problem with a small percentage of projects for many years. When tender mixes occur, typically, the mix can be rolled for 1-2 or more passes with a steel wheel roller before the mix begins to move laterally. After a few passes with steel wheel rollers and after the mix has had an opportunity to cool, the mix begins to act tender under the steel wheel rollers. This is not new with Superpave mixtures. Tender mixes have often occurred in the past, but the tender mix problem has been highlighted by increased attention on all aspects of Superpave. It does appear that the problem occurs most often with coarse-graded Superpave mixes than was observed in the past when using fine-graded mixes.

Tender mixes often are difficult to compact to the required density. Once the mix begins to move laterally, additional rolling results in further lateral movement and thus does not allow for adequate compaction. This lateral movement of the mix during rolling may result in a loss of bond to the underlying pavement layer. When this happens, slippage of the overlay may result during the life of the pavement.

The hairline cracks that sometimes result when rolling tender mixtures are usually very shallow and do not typically, by themselves, cause a significant problem. However, these cracks allow the mix to absorb moisture and may reduce the durability of the HMA. While these initial cracks are typically not a problem, they may provide a weakness in the HMA pavement that may result in crack growth and eventually premature failure.

Tender mixes that are compacted to the desired density level may not experience significant loss in life but the lateral movement during compaction will result in loss of smoothness. So even though these tender mixes may not result in loss of life, they will lower the overall pavement quality by increasing the roughness of the compacted mix.

Tender mixes may be caused by a number of factors, therefore, it is difficult to present a general mechanism that describes tender mixes for all cases. The most frequent description of how the lateral movement begins for tender mixes, follows. When the mix is placed, the mix temperature is approximately the same throughout the layer. At this point, the stiffness of the asphalt mixture is low since the mix temperature is high and the density is low. During the compaction process, the mix cools more rapidly on the top and bottom of the layer than it does near the middle. Since the mix remains hot longer in the middle of the layer there is a temperature and stiffness differential throughout the layer of HMA. When rolled in this condition, the steel wheel roller has a tendency to push the top portion of the mix laterally past the bottom portion. The mix is still soft enough, especially near the middle of the layer, to allow the roller to sink into the mix somewhat. This forms a small wave in front of the roller. Also remember that the asphalt binder acts as a lubricant at higher mix temperatures. As the roller is powered in one direction, it tends to force the top portion of the mix to move laterally relative to the bottom portion. The top portion of the HMA is now stiff enough so that the force of the roller pushes the mix and causes it to move a significant distance in front of the roller.

When the mix is loose and hot throughout, the roller can not force the mix surface to move laterally since the surface of the mix has little stiffness and therefore can not be pushed out in front of the roller. When the surface is cooled to about 240°F and is partially compacted, the stiffness near the surface will cause the stiffer top material to be pushed out in front of the roller. The surface of the mix moves because the mix in the center of the layer is not sufficiently stiff to prevent the movement. Once the mix has cooled to approximately 150°F on the surface, the mixture near the center of the layer typically has cooled and been compacted sufficiently to increase the stiffness enough to resist the lateral movement. The cohesion of the cooled asphalt also helps to prevent lateral movement at these lower temperatures.

CAUSES OF TENDER MIXES

Identifying the specific cause(s) of tender mixes on a given project is very difficult to do. There are a number of items that cause mixes to be tender and any one of these acting alone or in combination with other items may result in tenderness.

Potential causes of tender mixes are listed below:

- Moisture
- Excess Asphalt Content
- Rounded Aggregates
- Aggregate Gradation
- Inadequate Bond to Underlying Layer
- Excessive Mix Temperature
- Asphalt Binder Light Ends
- Rolling Equipment and Techniques
- Stiffness of Binder
- Contamination

Moisture can occur in several places that may result in the mix appearing tender. Excess moisture can be present in the mix when the aggregate is not properly dried. There can also be excess moisture on the existing pavement surface that may cause the mix to act tender when the surface is overlayed. The moisture increases the liquid content of the mix and thus decreases the internal strength of the mix during the compaction process. The moisture in the HMA at these high temperatures is being converted to steam which greatly increases the volume of the moisture. The steam exerts internal pressure on the mix that tends to push the aggregates apart as the mix is being rolled. These forces result in a decrease in internal strength when rolled causing the mix to act tender. In some cases, a small amount of moisture (within specification) may be sufficient to cause the mix to act tender.

Mixes that have excessive binder contents may cause compaction problems. Excessive binder content is a relative term and is a function of the mixture. When the binder content is high enough to restrict compaction of the mix, then the high binder content can cause the mix to act tender when rolled. When the mix is properly designed and controlled, this should not be a problem.

Rounded aggregates have long been associated with tender mixes. Rounded particles that may be found in sands and gravels often tend to cause the mix to act tender during compaction. It is much easier for the rounded aggregates than for more angular aggregates to roll past adjacent aggregates resulting in lateral movement during the compaction process.

Tenderness may be affected by aggregate gradation. For example, if the filler content is too low, the mix may act tender due to inadequate binder stiffness since some amount of filler is needed to provide adequate binder stiffness. In some cases, mixes with smaller nominal maximum aggregate size are more likely to be tender than mixes with larger nominal maximum aggregate size and in other cases the opposite is true. Generally, mixes with more uniform aggregate sizes are more likely to be tender than a more well-graded aggregate. Two examples of mixes with relative uniform aggregate sizes that are not generally tender are open-graded friction course

(OGFC) and stone matrix asphalt (SMA). The OGFC is not normally tender because it uses a very angular aggregate, the layer thickness is thin compared to nominal maximum aggregate size, the asphalt binder is typically relative stiff, and very little compaction is required. The SMA is not normally tender due to the high filler content, the relative stiff binder, and the use of fibers.

Mixes that otherwise may not be tender may act tender when there is inadequate bond to the underlying layer. When overlaying an extremely smooth oxidized pavement, it may be difficult to obtain a good bond regardless of the type and amount of tack coat used. The surface of some existing pavements may be loose and showing signs of loss of fine aggregate. It is difficult to get a good bond when overlaying these pavements. Cutting cores after compaction will clearly show if a bond problem exists between the two layers.

If too little or too much tack coat is applied, the mix may appear tender. Also, if the wrong type of tack coat is used, a good bond may not be obtained. A better bond and less lateral movement is generally obtained over a milled surface than over a surface that has relative smooth surface texture. Also, asphalt cements have sometimes been used as a tack coat and some results indicate that a better bond is obtained with the asphalt cement than with asphalt emulsions.

Mixes that are placed too hot are more likely to act tender than mixes placed at the proper temperatures. When a mix is placed too hot, the rollers may have to wait until the mix has cooled to begin rolling. Even though the surface of these mixes may be cool, the center of the mix is often still too hot and the mix will appear tender under the rollers. Mixes should generally be placed at the temperature at which rolling can begin immediately so that the rollers can roll immediately behind the paver.

Some asphalt cements have light ends that may be driven from the mix at 300-350°F. These light ends will have much the same effect as moisture at high temperatures on compaction of the mix. In some cases, these mixes with asphalt cements with excessive light ends may be very difficult to compact. There have been occasions when a change in the source of asphalt cement has solved the tenderness problem.

The rolling equipment and techniques have a significant effect on the way the mixture handles during compaction. Mixes that appear tender under steel wheel rollers will typically not act tender under rubber tire rollers. Quick stops and starts and sudden turns with a steel wheel roller are likely to shove a mix laterally. Once a mix begins to move laterally, each successive pass with the roller will typically result in increased movement. Heavier steel wheel rollers are more likely to cause a mix to act tender than lighter rollers however, the additional weight is generally needed to meet compaction requirements. Operating a steel wheel roller with the drive wheel on the front of the roller will minimize any lateral movement. However, the drive wheel has to be on the back of the roller when traveling either toward the paver, or away from the paver. Generally, it is better to have the drive wheel in the front when moving toward the paver.

The binder stiffness affects tenderness. When the binder is too hot, the stiffness is low and tenderness may result. Asphalt mixes containing polymers generally are stiffer when being rolled and are therefore less likely to be tender, if the breakdown rolling has been completed before the mat temperature cools to 275°F.

Contamination with diesel fuel or other petroleum solvents can cause tender mix problems. The solvents may come from contamination in asphalt binder storage tanks, release agents in the truck, incomplete burning of fuel oils, spills on the existing pavement, or many other sources. Care must be taken to ensure that no contamination occurs during the construction process otherwise tenderness and other problems are likely to exist.

All aspects of the construction process must be considered when evaluating a tender mix problem. The mix may be tender or may only appear tender due to lack of bond to the underlying layer or due to rolling equipment or procedures used.

STEPS TO SOLVE THE TENDER MIX PROBLEM

When a tender mix is observed, there are several steps that can be taken to minimize the problem or to work around the problem. First of all, if the mix has been placed previously with no tender mix problems, determine what has changed. Some possibilities include: change in moisture content, change in mix temperature, change in source of asphalt cement, change in tack coat, or change in roller or roller operator. These are the most likely causes of a mix acting tender at a given time when the same mix had not been tender earlier.

Sometimes, excess moisture can cause a mix to become tender. This excess moisture may result from a recent rainfall or getting into a wet portion of a stockpile. In this case, the immediate solution is to try to work the stockpile so that the amount of moisture going into the mixture is minimized. The long term solution may be to provide better drainage from the stockpile by using paved surfaces underneath the stockpile and/or to provide protection so that the stockpiles are not exposed to rainfall.

Due to long haul distances and possible delays, the HMA is often heated a few degrees above the normal range. A slight temperature change in the mixture may make the difference between a stable mix and an unstable mixture in the compaction process. If the mix is tender, try lowering the mix temperature approximately 10°F to determine the effect on tenderness. If there is some improvement in the mix during compaction and there is no detrimental effects in the workability of the mix and the ability of the asphalt cement to coat the aggregate, then consider lowering the temperature another 10°F. If the tenderness problem is solved and no other problems exist that are caused by the lower temperature, then continue producing mix at this lower temperature.

If lowering the temperature does not reduce the tenderness problem, then other options must be considered. Another option that may be considered is to compact the mixture before it reaches the tender zone. This may require that an extra roller be used for compaction so that the rollers can operate at an acceptable speed and still provide sufficient passes prior to the mix cooling to approximately 240°F (start of the tender zone). This process has been used successfully on many projects, but this approach is not always successful.

Another approach that has sometimes been used but is not recommended, is to roll the mix until it cools sufficiently to become tender, stop rolling until the mix cools sufficiently so that it is no longer tender, and then continue rolling below the tender zone. This process has been used successfully on some projects, but this approach may cause other problems. First, after the mix has cooled to these lower temperatures (typically, 150°F and less), the rolling is much more likely to break aggregate. This approach also carries more risk. When density can not be obtained using the approach, a large quantity of mix may be placed before the problem is recognized. If adequate density can not be obtained, then this large quantity of material may not be acceptable. If paving when rainfall is threatening, then the contractor needs to be able to quickly compact any mix in place or again, if rainfall begins, a lot of material may be wasted. Also, rolling at these lower temperatures may make it much more difficult to remove all roller marks and result in problems with roughness.

One approach that has been used successfully on many projects is to use a rubber tire roller when compacting in the tender zone. Experience has shown that rubber tire rollers do not shove the mix laterally (even when tender) like the steel wheel rollers. These rollers are very effective when used in the tender zone and are also effective when used with mixes that are not tender. The primary disadvantage of the rubber tire rollers is the tendency for the rubber tires to pick up asphalt. With some mixes, the HMA being compacted tends to stick to the rollers causing the surface to be non-uniform. A lot of work has been done to improve rubber tire rollers so that the pick up problem is minimized. Skirts are often placed around the rubber tires to minimize cooling of the tires, especially on windy days. The amount of pick up is minimized when the tires are hot. Recently, modifications have been made to the compounds used to manufacture some rubber tires so that the HMA has less tendency to stick to the tires. These new tires show some promise, but additional work is needed. For years, soapy water has been used to wet the tires. This procedure has helped in many cases but this does not always solve the problem. A silicon additive is now being evaluated that also shows some promise, but this work has not been finalized. The biggest pick-up problem occurs when using modified asphalts. If the pick-up problem can be solved, the tender zone problem can be handled very effectively with rubber tire rollers.

The information mentioned above provides guidance that can be readily implemented when the tender zone problem is encountered. There are a lot of other factors that are important as discussed earlier, but their implementation is more difficult.

SUMMARY

Although the problem with tender mixtures has been around for many years, it has attracted more attention now that Superpave mixes are being used. The problem does appear to occur more often with Superpave. It is estimated that the problem occurs to some degree on approximately 40 percent of the jobs. Generally, contractors have been able to work around the tender zone problems to get an acceptable mixture. From a performance standpoint, the biggest problem caused after a tender mix has been rolled (assuming adequate compaction) appears to be roller marks and the associated loss in smoothness.

This paper has documented some of the ways that have been used to solve the problem. It is important to remember that there are many possible causes for tender mix problems and therefore, the method that is used to solve the problem on one project may not be successful on another project. However, the guidance provided herein offers several alternatives that should be sufficient to solve most tender zone problems.