CONSTRUCTION OF DURABLE LONGITUDINAL JOINTS

James A. Scherocman, P.E.
Consulting Engineer
11205 Brookbridge Drive
Cincinnati, Ohio 45249 USA
513-489-3338
jim@scherocman.com

Revised September 1, 2008
INTRODUCTION:

The durability of longitudinal joints in asphalt concrete pavements is a major problem at many locations across North America. Because of maintenance of traffic considerations, most asphalt pavement resurfacing is done one lane at a time. One lane is paved and then the adjacent lane is paved, with a cold joint between the two lanes. After a short period of time under traffic, these joints tend to ravel. Typically, however, the raveling takes place only on one side of the joint. An example of this type of raveling is shown in Figure 1.

Sometimes the raveling at the longitudinal joint is severe enough to completely erode the surface course material adjacent to the joint and expose the underlying pavement layer, leaving a gap between lanes. This type of failure is illustrated in Figure 2. Not only is the long term durability of the pavement compromised, the safety of the traveling public is also a major concern.

Figure 1: Raveling at the longitudinal joint
Figure 2: Severe erosion of mix at the longitudinal joint

Longitudinal joints between traffic lanes or between the mainline pavement and the adjacent roadway shoulder can be properly constructed. Care must be taken to accomplish four primary tasks--compaction of the unsupported edges of the first lane paved, overlap of the mix on the second lane over the top of the first lane, raking of the mix off of the first lane, and compaction of the joint between the two lanes. Using the proper construction techniques, the cost of building a durable longitudinal joint is no more expensive than building a poor longitudinal joint.

MEASUREMENT OF JOINT DENSITY:

The measurement of the density at a longitudinal joint will typically not be equal to the density obtained in the mainline pavement mix even if all of the proper construction procedures are used. This is primarily due to the compaction of the unsupported edge of the first lane placed. In general, the density of the asphalt concrete mix will be less on the first lane side of the joint (lane 1) compared to the second lane side of the same joint (lane 2).
If cores are used to determine the density level obtained at a longitudinal joint, the location of the core becomes very important in the amount of density measured. If a core is cut more than 150 mm (6 inches) away from the center of the joint, on either side of the joint, the density measured in the core should be the same as for the internal mainline pavement. If a core is cut within a distance of 75 to 150 mm (3 to 6 inches) away from the center of the joint, the core density will be somewhat less depending on the tenderness of the mix and the transverse movement of the mix during the compaction operation. In this case, the density on the lane 1 side of the joint (unsupported edge) will typically be less than the density on the lane 2 side of the joint, within the distance of 75 to 150 mm from the center of the longitudinal joint.

Figure 3 shows a core cut directly over the center of the longitudinal joint. In this case, a 100 mm or 150 mm (4 or 6 inch) diameter core is centered on top of the visible line between the two lanes. It is noted that although the core is evenly spaced over the joint at the top of the asphalt concrete layer, the volume of mix in the core is not evenly distributed between the two lanes. This is due to the slope of the mix on the lane 1 side of the joint that is caused by the mix moving out from under the edger plate on the side of the screed of the paver on the unsupported edge. Most of the volume of the core cut from the center of the joint comes from the first lane paved. This means that the density of the joint measured from a core cut directly over the center of the joint will normally be less than the density of a joint measured from a core cut with an offset from the center of the joint.

![Figure 3: Core centered on the longitudinal joint](image)

Measurement of the density of the longitudinal joint using a nuclear density gauge is very problematic. In most cases, the elevation of the compacted mix on each side of the joint is not exactly the same. Typically, the mix on the lane 2 side of the joint is somewhat higher than the mix on the lane 1 side of the joint. This is due to the amount of mix placed on top of the first lane--both the width of the overlap and the height of the overlap. Due to the difference in height, a nuclear gauge generally does not sit flat when placed across the top of the joint. This increases the air gap under one side of the gauge and provides an inaccurate density measurement.

The density of the mix at the longitudinal joint, measured with cores centered on the joint, should be within 1.5 percent of the mainline mat density. If the requirements for the pavement are set at 92.0 percent of the theoretical maximum density, for example, it should be possible, with proper construction techniques, to achieve a minimum of 90.5 percent density at the center of the longitudinal joint. Most specifications for longitudinal joint density, however, set the required density level at 2.0 percent below the required mainline mat density.

**COMPACTION OF THE FIRST LANE:**

One of the keys to the construction of a durable longitudinal joint is proper compaction of the unsupported edge of the first lane of pavement placed. The mix placed by the paver will have a slope on its outside edge. The amount of slope depends on the type of end or edger plate on the paver screed but
typically is approximately 60 degrees. This wedge, which is shown in Figure 3, does not receive the same amount of compaction as the rest of the mix due to its shape and position.

The type of roller used and its position in regard to the unsupported edge of the pavement significantly affects the amount of density that can be obtained. A pneumatic (rubber) tire roller normally can not be used within about 150 mm (6 inches) of the unsupported edge of the lane without pushing the mix sideways due to the high pressure in the rubber tires. This is illustrated in Figure 4. For this reason, a rubber tire roller is not useful in compacting the asphalt concrete mix at the joint on lane 1.

![Figure 4: Edge of the rubber tires inside the unsupported edge of the pavement](image)

A steel wheel roller, however, can be operated in three different locations in regard to the unsupported edge of the lane. Two of those positions, however, do not provide the proper compactive effort needed to achieve the required amount of density.

As seen in Figures 5 and 6, if the edge of the drum of a steel wheel roller, operated either in the vibratory mode or in the static mode, is inside the unsupported edge of the pavement lane, two things may happen. First, the mix has a tendency to widen out--to move in a transverse direction. This is due to the shear loading on the mix at the edge of the steel drum. The amount of movement is dependent on the properties of the asphalt concrete mixture--a tender mix will shove or move more than will a stiff mixture. In addition, a crack will typically form at the edge of the drum, as shown in Figure 7. This crack is caused by the sideways movement of the mix. Further, the movement of the mix creates a dip at the unsupported edge of the lane, making it much more difficult to match the joint when the second lane is placed. Placing the edge of the roller drum inside the edge of the lane is not good practice.
The edge of the steel drum can be placed directly over the unsupported edge of the lane. This is shown in Figure 8. In this case, the mix at the unsupported edge will still move sideways or transversely under the force of the roller. Although the mix will widen out, no crack will typically form since the edge of the steel wheel roller drum is right at the edge of the lane. Due to the transverse movement of the mix, however, the opportunity to obtain density at the unsupported edge is not possible.

The proper location for the edge of the steel drum is illustrated in Figure 9. The drum is extended over the edge of the lane by approximately 150 mm (6 inches). In this case, there will be no transverse movement of the mix since there is no shear loading at the edge of the steel drum. Since the mix does not move transversely, no crack is formed. Density is achieved because the edge of the steel drum is compacting air instead of shoving the mix sideways. The proper location of the edge of the steel wheel roller drum over the unsupported edge of lane 1 is shown in Figure 10.
An example of the movement of the unsupported edge of the lane is shown in Figures 11, 12, and 13. In the first figure, Figure 11, the paver operator is placing the mix in a straight line. The unsupported edge of the mix is straight. The angle of the mix at the unsupported edge—about 60 degrees—is also seen in this same figure.

In Figure 12, a double drum vibratory roller is shown compacting the unsupported edge of the same stretch of pavement. Because the roller operator is not running the roller in a straight line, the edge of the lane is no longer straight. Where the edge of the steel drum is positioned over the unsupported edge of the lane, as where the roller is currently located in the picture, the mix remains in place and does not move transversely. In the foreground of the figure, however, the roller drum was inside the edge of the lane and the mix has moved sideways. The amount of transverse movement is directly related to the location of the edge of the steel roller drum relative to the unsupported edge of the asphalt pavement.
In Figure 13, the paver has moved farther down the roadway. The unevenness of the longitudinal joint is clearly evident. Again, where the edge of the steel drum was placed over the unsupported edge of the lane by approximately 150 mm (6 inches), no sideways movement of the mix occurred. Where the edge of the drum was either just at the edge of the joint or inside the unsupported edge by some small distance, the mix moved transversely under the shear loading at the edge of the drum. Matching this ragged joint when the second lane is placed next to this lane will be very difficult.

In order to construct a durable longitudinal joint, it is necessary to compact the unsupported edge of the first lane correctly. This is accomplished by extending the drum of a steel wheel roller over the unsupported edge of the lane by approximately 150 mm (6 inches). If this is done, the asphalt concrete mix will not move transversely and a crack will not form in the mix at the edge of the steel drum due to shear.
loading at the edge of the drum. This lack of movement will allow the second lane to be properly placed and compacted against the edge of lane 1.

**OVERLAP OF MIX FROM LANE 2 TO LANE 1:**

The second key to the construction of a durable longitudinal joint is related to the amount of overlap of the end or edger plate on the paver screed over the edge of lane 1 when placing mix for lane 2. Two items need to be considered. The first is related to the thickness of the uncompacted mix from lane 2 over the top of the compacted mix at the edge of lane 1. The second is related to the transverse amount of overlap of the mix from lane 2 over the top of lane 1.

Dense graded asphalt concrete mix typically compacts at a rate of 6 mm per 25 mm (1/4 inch per inch). This means to achieve a compacted thickness of 25 mm (1 inch), the mix usually must be placed from the back of the paver screed at an uncompacted thickness of about 31 mm (1-1/4 inches). Further, to obtain a compacted thickness of 50 mm (2 inches), the uncompacted mix must be placed to a thickness of approximately 62 mm (2-1/2 inches). When mix from lane 2 is placed over the top of the compacted mix on lane 1, the mix needs to be high by the amount of compaction that will occur.

The amount of overlap of mix from lane 2 onto lane 1 is critical in the construction of a durable longitudinal joint. If an excessive amount of mix is placed over the edge of lane 1, it will have to be removed by raking the joint or it will be crushed by the rollers. If not enough mix is placed over the edge of the first lane, a depression or dip will occur on the lane 2 side of the longitudinal joint. In either case, the joint will not perform properly under traffic. The amount of transverse overlap needed is in the range of 25 to 40 mm (1 to 1-1/2 inches) for proper longitudinal joint construction.

An excessive amount of overlap of the mix from the new lane (lane 2) onto the old lane (lane 1) is shown in Figure 14. In this figure, it appears that the edger plate on the paver screed is about 250 mm (10 inches) over the top of lane 1. With this excessive amount of mix placed on the compacted lane, it is necessary to remove the excess material by shoveling the extra mix off of the pavement, not by raking the mix onto the new lane.

The proper amount of overlap is illustrated in Figure 15. In this case, the amount of overlap is in the range of 25 to 40 mm (1 to 1-1/2 inches). Given this amount of overlap, no mix has to be moved off of the top of lane 1. No raking of the mix at the longitudinal joint is needed.

When milling of the existing asphalt concrete pavement surface is done, a vertical face is formed along the edge of the cutting head on the milling machine. This is significantly different than the slope that is formed by the edger plate on the paver screed. In this case, due to the vertical edge of the adjacent lane of compacted mix, the amount of overlap must be controlled very carefully. To properly construct the longitudinal joint, the amount of overlap of mix from lane 2 over the non-milled surface should be about 6 to 12 mm (1/4 to 1/2 inches), maximum.
RAKING THE LONGITUDINAL JOINT:

If the proper amount of mix is placed in the proper place, no raking of the mix at the longitudinal joint is necessary. If an excessive amount of mix is placed over the top of lane 1, removal of the excess mix with a shovel instead of pushing or raking the excess mix over the top of the new lane should be done. Thus the third key to a durable longitudinal joint is not to rake the joint during construction.

Figure 16 illustrates improper raking of the longitudinal joint. When raking is done, the amount of mix needed at the joint is usually pushed into the hot mix on lane 2 by the person doing the raking. By setting the rake down on the compacted mix of lane 1 and pushing the rake transversely into the mix at the joint, the mix is shoved on top of the hot mix on lane 2. This makes the mix too low on the lane 2 side, directly at the joint, and too high on the lane 2 side a short distance away from the joint. Essentially, the mix ends up at the same elevation of each side of the joint. The problem is that the mix on one side of the joint is compacted (lane 1) and the mix on the other side of the joint is not yet compacted (lane 2).

In order for the rollers to be able to compact the mix on the hot side of the longitudinal joint, the asphalt concrete mix must be high--6 mm for each 25 mm (1/4 inch for each 1 inch) of compacted thickness. If the joint is raked flat, the rollers will not be able to compress the mix since it will already be at the same elevation as the compacted mix in lane 1. This will result in very low density at the longitudinal joint on the lane 2 side of the joint.

As seen in Figure 16, the mix being placed is on a milled surface. The amount of overlap of the new mix over the vertical face of the mix on the old adjacent shoulder is about right--12 mm (1/2 inch) or less. The uncompacted mix is also high--in this case about 12 mm (1/2 inch) for a 50 mm (2 inch) compacted mix thickness. Thus the paver is placing the right amount of mix in the right place. The raker, however, is ruining the joint by removing the mix adjacent to the joint that needs to be compacted. In this case, the raker is pushing the mix that needs to be compacted at the joint into the interior of lane 2.
Sometimes a raker will attempt to “bump the joint” with the rake. In this case, the mix in the overlap of lane 2 on lane 1 is not pushed over the top of lane 2 but merely humped up at the joint. If the new mix is at the proper height, the extra material right at the joint will have no place to go vertically. This will result in a bump or ridge along the joint. The rollers will then have a tendency to ride on the ridge of extra mix and not be able to properly compact the hot mix adjacent to the ridge.

Proper raking of the mix on the lane 2 side of the joint is not raking the mix at all. Looking back at the illustration shown in Figure 1, it is easy to determine which side of the joint is the lane 1 side and which side of the joint is the lane 2 side. The left side of this joint was paved first—lane 1. The raker placed the rake down on the compacted mix on lane 1. The raker then pushed the overlapped mix across the top of lane 2 and into the interior of lane 2, not leaving the mix on the lane 2 side of the joint high enough to be properly compacted. Essentially the raker made the elevation of the mix on both sides of the joint—both the compacted and the uncompacted side—the same. This did not provide any mix for the rollers to compact. Given the low level of density on the lane 2 side of the joint, the mix raveled with the application of traffic.

If raveling occurs at the longitudinal joint, it is most often caused by the raking of the joint and the transverse movement of mix needed at the joint into the interior of the second lane. Raveling typically occurs on the lane 2 side of the longitudinal joint.

**COMPACTING THE LONGITUDINAL JOINT:**

The final key to constructing a durable longitudinal joint is the location of the rollers during the compaction of the mix at the joint. The rollers can be placed in several different transverse locations. Only one of those locations, however, provides for the efficient compaction of the longitudinal joint.

In the past, it was often common practice to compact the longitudinal joint from the lane 1 or the cold side of the joint. The steel wheel roller, operated in the static mode, was located with most of the drum on lane 1 with only 150 to 300 mm (6 to 13 inches) of the width of the drum extending over the joint and over lane 2. Such a compaction operation is illustrated in Figure 17.
This type of compaction operation, however, is very inefficient for a number of reasons. First, most of the weight of the roller is on the previously compacted mix. While the roller is moving over the cold mix, the temperature of the new hot mix in lane 2 is decreasing, thereby reducing the opportunity to obtain the desired level of density in the new asphalt concrete mix. Second, a vibratory roller cannot be operated in the vibratory mode on the cold side of the joint—on lane 1—since this may fracture the aggregate in the compacted mix. This reduces the amount of compactive effort that can be applied to mix at the joint. In addition, if there is a different cross slope between the two lanes such as when the joint is located at a crown section on the roadway, only a minimum amount of the weight of the roller will actually be in contact with the mix at the joint due to the different slopes between the two lanes. Rolling the mix from the cold side—the lane 1 side—is very inefficient and results in a significantly reduced amount of density in the mix at the joint.

Sometimes a steel wheel roller is placed just inside the longitudinal joint on the hot side of the joint—the lane 2 side. This is done to “pinch the joint” but is not good practice. With a steel wheel roller, if the mix being placed is tender, locating the edge of the steel drum some 150 mm (6 inches) inside the joint will result in the mix being pushed sideways, similar to the problem at the unsupported edge of the pavement on lane 1. Because of the side support from lane 1, however, the mix will simply hump up adjacent to the joint. This will result in a longitudinal ridge being formed along the lane 2 side of the joint. This, in turn, will result in poor compaction of the mix at the joint since the roller on subsequent passes over the joint will ride on the high spot in the mat—the ridge—and not compact the mix next to the ridge at the joint.

A much better place to position the roller, either a steel wheel roller or a pneumatic tire roller, is a short distance over the top of the joint from the hot side of the joint. If a rubber tire roller is used for compaction, the center of the outside tire of the roller, at the end of the roller with an even number of tires, is placed directly over the top of the longitudinal joint, as shown in Figure 18. Placing the roller in this position permits proper compaction of the mix at the joint as well as compaction of the hot mix on lane 2. This is an efficient way to compact both the mix at the joint and the mix in the mainline pavement.

For a steel wheel roller, the majority of the weight of the drum is placed on the hot mix on lane 2 with only 150 mm (6 inches) or so of the width of the drum extending over the top of the joint and over the top of lane 1. This is shown in Figures 19 and 20. Such a rolling pattern allows the roller to apply most of its weight to the new hot asphalt concrete material while still compacting the mix at the joint. In addition, if there is a different cross slope between the two lanes, rolling from the hot side of the joint—the lane 2 side—will typically achieve a higher amount of compaction at the joint.
In summary, when compacting the longitudinal joint between lanes 1 and 2, the rollers should not be placed on the cold side of the joint. The most efficient location to place the rollers, either pneumatic tire or steel wheel, is on the hot side of the joint with one tire or a small amount of the width of the drum (150 mm or 6 inches) extending over the top of the joint. This type of rolling pattern will result in higher compactive effort being applied to the mix at the longitudinal joint and thus higher density at the joint. In addition, by rolling from the lane 2 side, the new mix is being compacted at the same time as the mix at the joint, resulting in a more efficient overall compaction operation.

**CONSTRUCTION OF A WEDGE JOINT:**

Some governmental agencies require the construction of a wedge joint at the longitudinal joint. This type of joint is shown in Figure 21. The original purpose of the wedge joint was to allow traffic to safely pass over the longitudinal joint from one lane to another while minimizing the difference in the drop off between the lanes. This makes sense from a traffic safety standpoint at the time of construction, but normally does not provide for a very durable longitudinal joint over the long term.
The wedge joint is typically formed by attaching a piece of metal to the edger plate on the paver screed. This form is used to create both vertical face at the top portion of the unsupported edge and the wedge or slope at the bottom portion of the joint. In most cases, the height of the vertical face is approximately half of the depth of the pavement course. The width of the wedge is typically 300 mm (12 inches) for many projects where a wedge type joint is used.

Two problems typically occur with the construction of this type of joint. First, it is very difficult to properly compact the wedge section. Because of the narrow width of the wedge, a full size roller can not be used for compaction. Often a very small single drum, static, steel wheel roller is towed behind the paver over the wedge. The amount of compactive effort applied to the mix by this drum, however, is minimal. Depending on the width of the wedge, most of the weight of the roller rides on the adjacent, lower pavement surface and the outside end of the wedge receives little or no compaction. The slope of the roller drum is usually different than the slope of the top of the wedge. This lack of density in the wedge may provide for deterioration of the longitudinal joint, from the bottom up, within a few years.

Second, the vertical face at the top of the wedge joint is difficult to match when the second lane is placed adjacent to lane 1. This was discussed above in regard to paving against an adjacent vertical face. The amount of overlap between the mix placed on lane 2 over the top of the compacted mix on lane 1 must be kept to a maximum of 12 mm (1/2 inch).

Improved traffic safety at the time of construction may be offset by increased deterioration of the joint with time and traffic.

OTHER CONSIDERATIONS:

Some individuals believe that it is necessary to apply a tack coat to the unsupported edge of the first lane before mix in lane 2 is placed against that edge. There does not seem to be any definitive evidence that the application of a tack coat provides any benefit in terms of the long term durability of the longitudinal joint. In general, the application of the tack coat is not very uniform because the material is typically placed using hand spray methods. Further, even when placed using an asphalt distributor, the distributor does not always run in a straight line compared to the unsupported edge of lane 1. Thus the tack coat does not always end up evenly applied on the joint.

Paving in echelon is sometimes done with the idea of creating a hot longitudinal joint and eliminating future deterioration at the joint. In this process, one paver is used to place the mix in lane 1. A second paver is used to place the mix in lane 2. The two pavers are usually located within 10 m (30 feet) or so of each other. The ultimate performance of the mix at the longitudinal joint depends primarily on the amount of overlap of mix placed by the second paver over the top of the mix placed by the first or front paver. If that amount of overlap is kept to a minimum--less than 25 mm (1 inch)--an excellent longitudinal joint will be constructed. If the amount of overlap is too much or too little, however, either a ridge or a gap will be formed at the longitudinal joint.

Paving in echelon just for the purpose of creating a hot longitudinal joint is typically not very beneficial or economical. In most cases, the amount of mix produced at the asphalt plant governs the rate of paving. Most asphalt pavers, operated without any type of material transfer device, can place more than 600 tonnes (660 tons) of mix per hour. Splitting the plant mix production to two pavers instead of one simply increases the cost of placing the mix.
Sometimes it is believed that it is beneficial to cut back the unsupported edge of the first lane to eliminate the under-compacted mix at the edge of the lane and in the slope or wedge at the side of the joint. This is typically unnecessary. First, this is a very costly operation. Second, the cutting has to be done in a straight line so that the joint can be matched with the second pass of the paver. Third, the amount of overlap of mix on the second lane over the vertical face of the cut joint has to be carefully controlled--12 mm (1/2 inch) or less in overlap distance, similar to the vertical edge with a milled pavement. There does not seem to be any significant data which indicates that the cutting back the joint results in a more durable longitudinal joint on a long term basis.

SUMMARY:

If the longitudinal joint is properly constructed, there generally is no need to apply a tack coat to the unsupported edge of the first lane--lane 1. Further, if the longitudinal joint is properly constructed, there is no need to cut back the unsupported edge of the first lane before the second lane is placed adjacent to it. If the longitudinal joint is properly constructed, there is no need to use two pavers running in echelon.

Proper construction of the longitudinal joint between pavement lanes consists of four primary steps. First, the unsupported edge of lane 1 must be compacted by placing the drum of a steel wheel roller about 150 mm (6 inches) over the top of the unsupported edge--compacting air at the edge of the drum. Second, the amount of mix placed over the top of lane 1 when the mix in lane 2 is placed should be limited to a distance of 25 to 40 mm (1 to 1-1/2 inches). Third, the mix placed at the joint when the second lane is constructed should not be moved with a rake but should remain where placed by the edger plate on the paver screed. Last, the mix at the longitudinal joint should be compacted from the hot side of the joint--the lane 2 side--with the outside tire on the rubber tire roller directly over the joint or the drum of a steel wheel roller extending 150 mm (6 inches) over the top of the joint.

Durable longitudinal joints are a workmanship issue. Proper construction techniques will provide for a long life longitudinal joint without raveling or deterioration.
PAVING OPERATIONS CHECKLIST

Given below is a list of things that need to be done in order to achieve the construction of a high quality asphalt concrete pavement.

A. Haul Truck Loading at the Asphalt Plant:

1. If tandem or tri-axle end dump type trucks are used:
   a. The first drop of mix, approximately 40 percent of the total weight of the load, should be placed directly adjacent to the front bulkhead of the truck bed.
   b. The second drop of mix, approximately 40 percent of the total weight of the load, should be placed directly adjacent to the tailgate of the truck bed.
   c. The third drop of mix, approximately 20 percent of the total weight of the load, should be placed in the middle of the length of the truck bed, between the first two drops of mix.

2. If bottom dump (belly dump) type trucks are used:
   a. The first drop of mix, approximately 70 percent of the total weight of the load, should be placed directly over the discharge gate(s) in the center of the length of the truck bed.
   b. The second drop of mix, approximately 15 percent of the total weight of the load, should be placed in the top-front of the truck bed, adjacent to the first drop.
   c. The third drop of mix, approximately 15 percent of the total weight of the load, should be placed in the top-back of the truck bed, adjacent to the first drop.

B. Tack Coat Application:

1. The distributor used to apply the tack coat should maintain the tack coat material at the proper application temperature at all times, approximately 160°F for asphalt emulsion and 320°F for asphalt cement.

2. All of the nozzles on the distributor should be completely open and functioning. The nozzles should be set at an angle of approximately 30 degrees to the axis of the spray bar.

3. The residual amount of asphalt cement remaining on the pavement surface should normally be in the range of 0.04 to 0.06 gallons per square yard.
   a. If an undiluted asphalt emulsion is used for the tack coat, the application rate (from the spray bar) should be 0.06 to 0.09 gallons per square yard.
   b. If an emulsion which has been diluted 1:1 with water is used for the tack coat, the application rate should be 0.12 to 0.18 gallons per square yard.
   c. If an asphalt cement is used for the tack coat, the application rate should be the same as the residual rate--0.04 to 0.06 gallons per square yard.

4. The residual asphalt cement should cover approximately at least 95 percent of the pavement surface.

5. The tack coat material must be allowed to break and set before the haul trucks are permitted to drive over the tack coat. The tack coat material should not be picked up on the tires of the haul trucks and carried away.
C. Unloading the Haul Trucks at the Paver:

1. If tandem or tri-axle end dump type trucks are used:
   a. The truck bed should be raised up into the air, with the tailgate closed, just high enough for the mix to shift toward the rear of the truck bed. It is noted that the tailgate latches must be properly maintained so that they keep the tailgate closed with the weight of the mix against the gate and then open when the latch is pulled.
   b. Ideally, the truck should stop about one foot short of contact with the paver. The paver should start moving forward and come in contact with the haul truck, not vice-versa.
   c. The tailgate should be opened, allowing a mass of mix to flow into the hopper of the paver.
   d. With about 20 percent of the load still remaining in the truck bed, the bed should be raised completely up into the air to allow the rest of the mix to slide as a mass into the paver hopper.

2. If bottom dump (belly dump) type trucks are used:
   a. The mix should be emptied from the truck and placed in the windrow in normal manner.
   b. The mix placed in the last few feet of the windrow should be examined to see if there is an excessive amount of coarse aggregate in that mix at that point.
   c. If excess coarse aggregate is found in the mix, the last ten percent of the load should be spread out, down the length of the roadway, instead of concentrated at the end of the windrow.
   d. The next truck load of mix should be spread out over the top of the extended windrow.

D. Amount of Mix in the Paver Hopper:

1. If tandem or tri-axle end dump type trucks are used:
   a. The amount of mix remaining in the hopper of the paver between truckloads of mix should be above the top of the tunnels (above the bottom of the flow gates) at the rear of the hopper--the hopper should be “half full” at all times.
   b. The sides (wings) of the hopper should NOT be raised between truckloads of mix. Mix should NOT be dumped out of the front of the hopper onto the pavement in front of the paver and then run over by the paver.
   c. Fillets should be installed in each corner of the hopper in order to prevent the accumulation of mix in the corners of the hopper. If this is done, it will NOT be necessary to fold the sides of the paver hopper between truckloads of mix.
   d. If the fillets are not used, the sides of the paver hopper should still NOT be raised during the paving day. Mix should be allowed to accumulate in the corners of the hopper and then removed and wasted at the end of the day.
   e. When the truck bed is empty, the paver should be stopped quickly--rapid stop--with the hopper still half full of mix. The paver should NOT be slowed down gradually.
   f. When the next haul truck delivers mix into the paver hopper, the paver should be started quickly--rapid start--and return to paving speed quickly.

2. If bottom dump (belly dump) type trucks are used:
   a. The amount of mix (thickness) remaining on the pavement surface under the paver (not picked up by the windrow elevator) should be minimized.
   b. When waiting for the delivery of mix, the paver should pick up as much of the length of the mix in the windrow as possible, leaving a minimum amount of mix in the windrow exposed on the pavement surface in front of the paver.
   c. The sides (wings) of the hopper should be folded against the sides of the windrow elevator to minimize the amount of mix retained in the corners of the paver hopper. As an alternative, fillets should be installed in each corner of the hopper in order to prevent the accumulation of mix in the corners of the hopper.
d. When there is no mix remaining in the windrow, the paver should be stopped quickly--rapid stop, with the hopper half full of mix. The paver should NOT be slowed down gradually.

e. When the next haul truck delivers mix into the windrow, the paver should be started quickly--rapid start--and return to paving speed quickly.

E. Delivery of Mix to the Augers and Operation of the Augers:

1. The conveyors in the bottom of the paver hopper should ideally run 100 percent of the time, continually delivering mix back to the augers.
2. The flow gates (if present) should be set at an elevation to permit the conveyors to run 100 percent of the time.
3. The augers should be set at a speed to permit continual operation--slowly enough to not throw mix to the end (side) plates on the screed but fast enough to prevent the buildup of mix at the center of the screed.
4. The amount of mix on the augers should be maintained at the center of the auger shaft. The augers should never be relatively empty or overfull. The bottom of the augers should never be visible. The top of the augers should always be visible. The head of material in front of the screed should be constant.
5. Reverse augers or reverse paddles should be installed adjacent to the gearbox (drive chain box) on the augers to feed mix under the gearbox to prevent the formation of a centerline streak behind the paver screed.

F. Operation of the Paver Screed:

1. Four forces affect the angle of attack of the paver screed. In order for a smooth pavement surface to be constructed, three of the four forces should remain constant. Those four forces are related to the head of material (amount of mix) in front of the screed, the speed of the paver, the elevation of the tow point on the paver, and the operation of the manual thickness controls.
2. The head of material (amount of mix) in front of the screed should be constant at all times. The conveyors and augers should operate 100 percent of the time.
3. The speed of the paver should be constant at all times, except for rapid stop--rapid start operation between truckloads of mix.
4. The speed of the paver should match the amount of mix being delivered to the paver. The paver should be operated at as slow a speed as possible and still efficiently empty all of the trucks.
5. The paver speed should not be increased just because a few trucks are waiting to unload in front of the paver. Similarly, the paver speed should not be gradually decreased just because no trucks are waiting. Rapid stop--rapid start is the method to be used to maintain a consistent angle of attack of the paver screed.
6. The tow point elevation should remain constant as the paver moves down the roadway over the underlying pavement surface. The paver will average out variations in the pavement surface over the length of the wheelbase of the paver. Thus the paver will level, placing less mix on the high points of the pavement surface and more mix in the low spots of the pavement surface.
7. The screed operator MUST refrain from trying to help the paver by changing the angle of attack of the paver screed manually. When the thickness controls are manually changed, it takes five times the length of the tow arm for the change in the angle of attack (and the change in the thickness of the layer being constructed) to fully occur.
8. The paver screed should be operated in the vibratory mode at all times. This significantly increases the amount of compaction achieved in the mix since the mix temperature high and can reduce the number of roller passes needed to complete the compactive effort.
G. Paver Screed Extensions:

1. If rear mounted screed extensions are used:
   a. Auger extensions are not normally needed unless the width of the extension is greater than the width of the hydraulic extension itself—no additional rigid screed extension width is used.
   b. An excessive amount of mix should not be allowed to accumulate in front of the extensions. The volume of mix carried in front of the screed extensions should be minimized.
   c. If a change in the width of paving is needed, that change should be anticipated by increasing or decreasing the amount of mix in front of the extension BEFORE the change is made.
   d. The feed of mix to the extensions from the paver augers should be continuous. The augers should run 100 percent of the time in order to keep the amount of mix in front of the screed extension constant.

2. If front mounted screed extensions are used:
   a. Auger extensions are not normally needed unless the width of the screed extension is greater than approximately two feet. If the screed is extended to a width greater than two feet, it is generally good practice to install auger extensions.
   b. An excessive amount of mix should not be allowed to accumulate in front of the extensions. The volume of mix carried in front of the screed extensions should be minimized.
   c. If a change in the width of paving is needed, that change should be anticipated by increasing or decreasing the amount of mix in front of the extension BEFORE the change is made.
   d. The feed of mix to the extensions should be continuous from the paver augers. The augers should run 100 percent of the time in order to keep the amount of mix in front of the screed extension constant.
   e. The strikeoff (or pre-strikeoff) in front of the main (trailing) screed should be set at an elevation to assure that the proper amount of mix is allowed to flow back to the main screed and tearing of the mix does not occur under the main screed due to a lack of mix.

3. For either type of screed extensions:
   a. The angle of attack of the extensions must match the angle of attack of the main screed so that the surface texture of the mix is uniform across the width of all the screeds.
   b. The elevation of the extensions must match the elevation of the main screed so that a different thickness of mix is not placed under the extensions compared to the main screed and a longitudinal line is not created at the point where the main screed and the extensions overlap.

H. Automatic Grade and Slope Controls:

1. If automatic grade controls are used on the paver:
   a. The length of the external reference (ski) should be longer than the wheelbase of the paver.
   b. The grade sensor must be set in the middle of the length of the ski.
   c. The center of the length of the ski should be located approximately at the tow point on the paver.

2. If automatic grade controls are used on the paver, an “over-the-screed” type external reference should be considered. A portion of the ski is located, longitudinally, in front of the screed and a second portion of the ski (or plate-type shoe) is located behind the paver on top of the mix just placed by the paver.

3. When automatic slope control is used on the paver, the slope control should be used toward the outside of the paving lane with grade control used on the inside (centerline) side of the paver.
I. Transverse Joint Construction:

1. At the end of the paving lane, the transverse joint must be located at a point where the pavement thickness is constant. The joint should not be constructed at the place where the paver runs out of mix. The location at which the head of material on the augers in front of the screed just starts to decrease is the point where the transverse joint should be constructed.

2. While the wedge or taper (elevation transition) is being constructed, the rollers should compact the mix as close to the joint location as possible, given the safety of the people constructing the transverse joint. The rollers should not hang back 10 or 15 feet from the joint. The mix will cool too much during the time that the joint is being constructed.

3. The mix in the wedge or taper should be completely removed when paving continues at the joint.
   a. The face of the transverse joint should be vertical. The joint should be cut back, if necessary, to the location where the pavement thickness is constant.
   b. The bond breaking material used under the wedge or taper should be completely removed.

4. When the paver is ready to place additional mix at the downstream (far) side of the joint:
   a. The screed MUST be set up on “blocks” or pieces of wood to assure that the elevation of the uncompacted mix downstream of the joint matches, after compaction, the elevation of the previously compacted pavement upstream of the joint.
   b. The thickness of the blocks should be 1/4 inch per inch of compacted mix thickness. For a two inch compacted layer, the thickness of the blocks under the screed should be 1/2 inch.
   c. At least three blocks should be placed under the main screed. At least two blocks should be placed under each of the screed extensions.

5. The front edge of the screed must be set directly over the vertical face of the transverse joint.
   a. If this is done, NO raking of the transverse joint is needed.
   b. If a paver with an extendable screed is used, the forward screed (the extension on a front mounted extendable screed and main screed on a rear mounted extendable screed) should be set directly over the vertical face of the transverse joint.
   c. Any mix that is placed on top of the compacted pavement, on the upstream side of the joint, should not be broadcast onto the new mix. The mix should be removed with a shovel and placed on the side of the roadway for future pickup.

6. The mix at the transverse joint should NOT be moved with a rake. There is no reason to do so since the elevation of the uncompacted mix will be at the correct height.

7. The transverse joint should be compacted in a longitudinal direction with the breakdown roller.
   a. There is no need to cross-roll the joint.
   b. The mix at the joint should be rolled as soon as possible after the paver has pulled away from the joint.

J. Longitudinal Joint Construction:

1. The unsupported edge of the longitudinal joint on the first lane constructed should be compacted as soon as possible after construction.
   a. Compaction should be accomplished with a vibratory steel wheel roller operated in the vibratory mode for each and every pass over the unsupported edge of the longitudinal joint.
   b. The vibratory roller should be operated at the highest possible frequency setting.
   c. The edge of the steel drum should extend over the unsupported edge of the joint by about 6 inches. If this is done, the mix should NOT move sideways during the compaction process.
   d. In no case should the edge of the steel drum roller be directly on top of the edge of the joint.
   e. In no case should the edge of the steel drum roller be inside the edge of the joint.
   f. The edge of the outside tire on a pneumatic tire roller should be kept 6 inches inside the edge of the joint on each and every pass of this type of roller.
g. The edge of a steel wheel roller operated in the static mode should also extend over the unsupported edge of the joint by about 6 inches on each and every pass of the roller.

2. When the second lane is being constructed against the compacted first lane of mix and the mix at the longitudinal joint has NOT been cut back to a vertical face:
   a. Tack coat is NOT needed along the longitudinal joint.
   b. The edge or side plate on the paver screed should extend no more than 1-1/2 inches over the top of the compacted mix on the first lane.
   c. The uncompacted mix placed on top of the compacted first lane should be 1/4 inch high for each inch of compacted lift thickness.
   d. The overlapped mix should NOT be moved with a rake. If the right amount of mix is placed in the right place, there is NO reason to rake the longitudinal joint.

3. When the second lane is being constructed against the compacted first lane of mix and the mix at the longitudinal joint has been cut back to a vertical face:
   a. Tack coat is NOT needed along the longitudinal joint.
   b. The edge or side plate on the paver screed should extend no more than 1/2 inch over the top of the compacted mix on the first lane.
   c. The uncompacted mix placed on top of the compacted first lane should be 1/4 inch high for each inch of compacted lift thickness.
   d. The overlapped mix should NOT be moved with a rake. If the right amount of mix is placed in the right place, there is NO reason to rake the longitudinal joint.

4. The longitudinal joint between the first and second lanes should be compacted using the following procedure:
   a. If a vibratory steel wheel roller is used for compaction, the roller should operate from the hot side of the joint with about 6 inches of the steel drum hanging over the cold side of the joint on each pass of the roller.
   b. The vibratory roller should operate at the highest possible frequency setting and an amplitude setting that is appropriate for the thickness of the layer being compacted. Every pass of the vibratory roller should be made with the roller in the vibratory mode.
   c. If a pneumatic tire roller is used for compaction, the center of the outside tire of the roller should be located directly over the top of the joint between the two lanes.
   d. If a static steel wheel roller is used for compaction, the roller should operate from the hot side of the joint with about 6 inches of the steel drum hanging over the cold side of the joint.
   e. The longitudinal joint should NOT be rolled from the cold side of the joint.
   f. The longitudinal joint should NOT be rolled with half of the roller on the hot side of the joint and half of the roller on the cold side of the joint.

K. Time Available for Compaction:

1. Asphalt concrete mixtures cool quickly. A number of factors directly affect the rate of cooling. The two most important factors are the temperature of the mix as it passes out from under the screed of the paver and the thickness of the layer. The ambient air temperature and the temperature of the surface on which the mix is placed is of secondary importance. Wind velocity, however, can have a significant affect of the rate of cooling.

2. The time available to compact the mix can be increased by:
   a. Increasing the mix temperature behind the paver screed.
   b. Increasing the thickness of the layer being placed.
   c. Paving on a day with higher ambient air temperature.
   d. Paving on a calm day instead of a windy day.

3. Initial (breakdown) rolling must be accomplished immediately behind the paver.
4. Intermediate rolling must be accomplished immediately behind after the initial rolling is completed.
5. Finish rolling, if needed, should be accomplished at a mix surface temperature above 180°F.
L. **Roller Operation:**

1. A vibratory roller should be operated under the following criteria:
   a. There is a direct relationship between roller speed, vibratory frequency, and the number of impacts per foot of roadway length. It has been determined that a minimum of 10 impacts per foot of distance is necessary to assure proper compaction and smoothness of the asphalt mix.
   b. A vibratory roller operated at a frequency of 2,400 vibrations per minute (vpm) can operate at a speed of approximately 2.7 miles per hour (mph) and maintain an impact spacing of 10 impacts per foot.
   c. A vibratory roller operated at a frequency of 3,000 vpm can operate at a speed of about 3.5 mph and achieve an impact spacing of 10 impacts per foot.
   d. A vibratory roller operated at a frequency of 4,000 vpm, however, can operate at a speed of 4.7 miles per hour and accomplish the same minimum impact spacing.
   e. The higher the frequency, the higher the roller speed, and the greater the density achieved before the mix cools below a compaction cutoff temperature of about 175°F.

2. The amplitude setting of the vibratory roller should be set with consideration of the thickness of the layer being compacted.
   a. If the compacted layer thickness is 1 inch or less, it is generally not advisable to operate the vibratory roller in the vibratory mode.
   b. If the compacted layer thickness is greater than about 1-1/4 inches and generally less than 2-3/4 inches, the vibratory roller should be operated at a lower amplitude setting.
   c. If the compacted layer thickness is 3 inches or greater, the vibratory roller can be operated at a higher amplitude setting.
   d. Using a high amplitude setting to compact a thin lift of mix often results in significant fracture of the coarse aggregate in the asphalt concrete mix.

3. The pneumatic tire roller should be operated under the following criteria:
   a. The tire pressure in each tire should be the same.
   b. For the compaction of stiff mixes, the tire pressure should be in the range of 90 to 100 pounds per square inch (psi).
   c. For the compaction of tender mixes, it may be necessary to reduce the tire pressure to a range of 75 to 85 psi.

M. **Compaction of Stiff Mixes:**

1. Stiff asphalt concrete mixtures are mixes that do not move under a steel drum roller (operated in either the vibratory or static mode), do not have a bow wave in front of the steel drum, and do not crack or “check” during the compaction process.
2. The most efficient process to compact a stiff mix is to use a pneumatic tire roller in the initial or breakdown roller position. At least three passes of the pneumatic tire roller are made over each point in the pavement surface, except the roller is kept at least 6 inches inside the unsupported edge of the pavement at the longitudinal joint.
3. The pneumatic tire roller is then followed by one or two double drum vibratory rollers (operated in echelon if two vibratory rollers are used). The vibratory rollers are operated at the highest possible frequency setting and at the proper amplitude setting for the thickness of the layer being compacted. Each vibratory roller should make at least three passes over the top of the pavement surface, including extending 6 inches over the edge of the unsupported longitudinal joint.
4. If two vibratory rollers are used in echelon, the make and model of the vibratory rollers should be the same in order to achieve the same level of density on each side of the lane.
5. Typically, no finish rolling is needed since this rolling is essentially accomplished through the use of the vibratory roller(s) in the intermediate position.
6. The most efficient roller pattern to compact a stiff asphalt concrete mix typically consists of a pneumatic tire roller in the breakdown (initial) position followed immediately by one or two double drum vibratory rollers operated in the vibratory mode (in echelon if two vibratory rollers are used).

N. Compaction of Tender Mixes:

1. Tender asphalt concrete mixtures are those mixes that have a “middle temperature zone” where the mix moves under the compactive effort of a steel drum roller, operated in either the vibratory or static mode. The mix checks when the bow wave is formed in front of the steel drum.

2. The temperature range associated with the middle temperature (tender) zone varies widely depending on the characteristics and properties of the asphalt concrete mix. For most tender mixes, the tender zone is in the range of 240°F down to perhaps 190°F.

3. Compaction of the mix in the upper (stable) temperature zone is carried out using two double drum vibratory rollers operated in echelon directly behind the paver. At least five passes of a steel drum roller are made over each point in the pavement surface. The make and model of the two vibratory rollers should be the same.

4. If necessary, a pneumatic tire roller can be used in the intermediate (middle) position—in the tender zone. The pneumatic tires will not shove the mix and will not create a bow wave like a steel drum roller will.

5. If a pneumatic tire roller is used, it is necessary to use a static steel wheel roller as a finish roller to remove the marks made by the pneumatic tire roller and to smooth out the pavement surface.

6. If a pneumatic tire roller is not used, a finish roller is most often NOT needed. A tender mix will compact very readily and, most often, an adequate level of density can be obtained by using only the two double drum vibratory rollers in the initial or breakdown position.

7. The most efficient roller pattern to compact a tender asphalt concrete mix typically consists of two double drum vibratory rollers operated in echelon in the breakdown (initial) position without any additional rollers being needed.
SEGREGATION:

CAUSES AND CURES

James A. Scherocman, P.E.
Consulting Engineer
11205 Brookbridge Drive
Cincinnati, Ohio 45249
Email: jim@scherocman.com

Revised September 1, 2008
INTRODUCTION:

Segregation in a Hot Mix Asphalt (HMA) mixture can be defined as the separation of the coarse aggregate particles in the mix from the rest of the mix. The segregation can take one of three forms--random, side to side or longitudinal, and truckload to truckload. Each type of segregation is caused by a different problem or problems. Each type of segregation, however, affects the long term durability of the asphalt concrete pavement structure.

Segregated areas in the surface of the pavement have a rougher texture than the surrounding pavement area. In addition, the density of the mix is much lower in the segregated locations compared to the density of the HMA mix in non-segregated areas. Pavement deterioration of the segregated areas in the form of raveling typically occurs quickly under traffic. With more time and with traffic loading, the raveled areas can increase in both size and depth, with a pothole forming in the pavement surface. With additional time and traffic, it is possible for the raveling to progress completely through the pavement layer.

This article will briefly describe the various causes for each of the three types of segregation. In addition, it will discuss the most efficient means to prevent each type of segregation from occurring. Emphasis will be placed, however, on the problem of truckload to truckload type segregation.

RANDOM SEGREGATION:

Areas of random segregation, shown in Figure 1, occur at irregular intervals in the surface of the roadway. These locations are indeed random, both transversely and longitudinally. In general, there is not any consistent pattern to the occurrence of the segregated areas.

Random segregation is primarily caused by the handling of the coarse aggregate materials as they are stockpiled and then fed into the asphalt plant. If a stockpile of coarse aggregate is built using a conveyor and a conical pile if formed, the largest aggregate particles typically roll down the sides of the pile and collect at the bottom of the pile. This is illustrated in Figure 2. If the operator of the front end loader at the asphalt plant picks up a bucket-full of the aggregate from the bottom of the pile and delivers the large aggregate particles into the cold feed bins at the plant, random segregation may occur on the roadway behind the paver, depending on the type of asphalt plant being used.
If a batch plant is employed to produce the asphalt concrete mix, the use of screens and hot bins at the top of the plant tower will normally partially reblend the segregated coarse aggregate. In addition, the mixing of the different size aggregates and the asphalt cement binder in the plant pugmill will also aid in reblending the segregated large, coarse aggregate particles. If the front end loader operator fills the cold feed bins with several consecutive bucket loads of large aggregate pieces from the bottom of the stockpile, random segregation may still occur on the roadway even when a batch plant is used to manufacture the HMA mix.

If a parallel flow drum mix plant is used to produce the mix, there is a significantly greater chance to obtain random segregation on the roadway if only large aggregate particles are delivered into the cold feed bins by the front end loader operator. Remixing of the aggregate particles in a parallel flow drum mix plant is limited before the asphalt cement binder material is added to the coarse and fine aggregates. It is often said that this type of plant operates on a segregated in-segregated out principle. If segregated large aggregate particles are in the cold feed bin, segregated mix will come out of the discharge chute of the plant.

If the HMA mix is manufactured in a counter flow drum mix plant, there is a greater opportunity for the large, coarse aggregate particles to be reblended inside the aggregate drying portion of the length of the drum. This is because the asphalt binder material is not added to the combined coarse and fine aggregates until the aggregates reach the rear mixing portion of the length of the drum. Although not as efficient in remixing the large aggregate particles together as the pugmill on the batch plant, the amount of random segregation that may be produced through a counter flow drum mix plant is usually much less than the amount of random segregation that may be produced when the HMA mix is manufactured in a parallel flow drum mix plant.

Once the segregated mix is produced in the plant, it is very difficult, if not impossible, to remix the segregated material during the temporary storage, loading, hauling, unloading, or paving processes. Thus the solution to a random segregation problem is found in the proper management of the coarse aggregate stockpiles at the asphalt plant.

If conical aggregate stockpiles are used, the front end loader operator must be aware that the largest aggregate particles within each coarse aggregate stockpile will roll down to the bottom of the pile. The loader operator then needs to do two things. The first is to rework the pile, reblending the large aggregate pieces at the bottom of the pile with the rest of the aggregate. The second is to fill the loader bucket with
non-segregated aggregate taken from the pile several feet above the ground level. It is obviously very important to consistently put uniformly graded coarse aggregate into the cold feed bins on any type of asphalt plant. In general, however, random segregation is not a major problem on most asphalt paving projects.

**SIDE TO SIDE OR LONGITUDINAL SEGREGATION:**

Side to side, or longitudinal segregation, shows up on the paved surface as a very rough texture on only one side of the paver. This is illustrated in Figure 3. This type of segregation is not caused by the mismanagement of the coarse aggregate stockpiles or by the loading of the aggregate into the cold feed bins or by the passage of the aggregate through the plant. Further, this type of segregation is not caused by the discharge of the mix from a parallel flow or a counter flow drum mix plant or the discharge of the mix from the pugmill from a batch plant.

![Figure 3: Side-to-side segregation](image)

In order for the segregated coarse aggregate material to end up on only one side of the paving lane, the asphalt concrete mix must roll downhill. The largest aggregate particles will separate from the rest of the mix, similar to what happens in a conical aggregate stockpile. This process can occur then the HMA mix is delivered into a surge silo from a drag slat conveyor, a bucket elevator, or from a conveyor belt.

When the mix is carried to the top of the silo, it must be placed into the center of the silo. Although a conical shaped pile of mix may build up inside the silo, the largest aggregate particles in the mix should roll downhill relatively equally all the way around the pile. As the silo is emptied, the coarse material will get mixed back into the remainder of the mix and longitudinal segregation will not occur.

Depending on the configuration of the silo and the type of conveying device employed, it is possible for the mix to be delivered into the top of the silo “off-center”, as shown in Figure 4. If this is the case, the pile of mix inside the silo will be higher on one side of the silo than on the other side of the silo. The higher side will be against the wall farthest from the discharge point of the mix from the conveying device. This provides the opportunity for the largest aggregate particles in the mix to roll downhill and collect at the side of the silo that is closest to the conveyor. These large aggregate particles will then be drawn down and through the silo and discharged into one side of the haul truck.
Side to side or longitudinal segregation can occur at the top of the silo even when a batcher is used to collect the mix coming up the conveying device and discharge the mix in a mass into the silo. If the mix delivered into the batcher is not placed into the center of the batcher, as illustrated in Figure 5, the largest aggregate particles in the HMA mix will roll to one side of the batcher. When the batcher is emptied, the segregated mix will be deposited on one side of the silo. This will result in side to side segregation of the mix behind the paver.

![Figure 4: Delivery of mix into the silo from a conveyor](image1)

![Figure 5: Delivery of mix into the silo from a batcher](image2)

Longitudinal segregation can also occur when mix is delivered “off-center” from a transfer conveyor running horizontally across the top of several silos. If the mix is pushed off the side of the conveyor, the largest aggregate particles in the mix can again be thrown against the far side of the silo. This, again, results in the largest aggregate particles running downhill to the near side of the silo. When the mix is discharged from the silo into the haul truck, the segregated material will be deposited on one side of the truck bed.

If the largest aggregate particles end up on one side of the haul truck, they will be discharged into the paver hopper on the same side. The segregated material will then pass through the paver on that side and come out under the screed only on that same side of the paver. Side to side segregation is caused by how (where) the asphalt concrete mix is delivered into the silo at the top of the silo. In general, however, side to side or longitudinal segregation is not a major problem on most asphalt paving projects.

**TRUCKLOAD TO TRUCKLOAD SEGREGATION:**

Truckload to truckload type segregation, sometimes incorrectly called end of load segregation, is shown in Figure 6. This type of segregation typically occurs as two very rough textured areas in a transverse direction, one on each side of the centerline of the asphalt paver. The size of the segregated area is dependent on whether or not the paver is moving forward when the segregated HMA mix passes under the paver screed. If the paver is stopped, the segregated areas will normally be relatively small and concentrated in two slightly oblong shapes, generally no more than five feet long. If the paver is moving as the segregated material passes under the paver screed, the segregated areas will occur at two long, longitudinal ovals, up to 15 feet in length.
Figure 6: Truckload to truckload segregation

It is often believed that truckload to truckload type segregation has a variety of causes. Most of those incorrect beliefs are related to the production of the HMA mix at the asphalt plant. Segregation of the coarse aggregates in the plant stockpiles, improper loading of the cold feed bins with segregated materials, variation of the aggregate feed into the asphalt plant, separation of the coarse aggregate particles from the rest of the aggregate inside the mixing drum, and improper discharge of the mix from the drum onto the slat conveyor—all of these factors are mentioned as possible causes of truckload to truckload segregation. In fact, none of these are the cause.

It is often believed that truckload to truckload segregation is related to the operation of the surge silos at the asphalt plant. Transport of mix up the slat conveyor, delivery of the mix at the top of the silo, either directly into the silo or into a hopper or “batcher” at the top of the silo, free fall of the mix into a silo which is relatively empty, and not keeping mix in the silo above the top of the cone—all of these factors are mentioned as additional possible causes of truckload to truckload segregation. In fact, none of these are the cause.

It is common sense why none of these potential problem areas are the cause of truckload to truckload segregation. In essence, if the largest aggregate particles in the mix separated from the rest of the mix at any of these locations, it would be almost impossible for those particles to collect ONLY at the end of a truckload of mix. It would be virtually impossible for those particles to collect at the end of each truckload on a continuous basis—truckload to truckload to truckload.

Loading the Haul Truck:

The primary cause of truckload to truckload segregation is the delivery of the HMA mix from the silo into the haul truck. Segregation of the mix occurs just as segregation of the aggregate occurs when the material is dropped on top of a conical pile. The largest aggregate particles in the mix roll down the sides of the pile and collect at the bottom of the pile.

Figure 7 shows the loading of an end dump haul truck from the silo at an asphalt plant. In this case, all of the mix is delivered into the truck bed in one drop. As the mix builds up in the truck bed, the largest aggregate particles in the mix begin to roll downhill. Those particles roll to the front of the bed, the sides of the bed, and to the back of the bed or to the tailgate on the truck. In the drop of mix is deposited into the middle of the length of the truck bed, then an equal amount of coarse aggregate (segregated material) will roll to both the front and the back of the truck bed. If the mix is deposited more to the front of the truck bed, which is typically the case for weight distribution, more large aggregate particles will roll to the tailgate area on the truck.
Truckload to truckload segregation is really a combination of two factors. The first part consists of the segregated material which comes out of one truck last--the large aggregate which collects at the front of the truck bed. The second part consists of the segregated material which comes out of the next truck first--the large aggregate which collects at the tailgate of the truck bed. Since most end dump trucks tend to be loaded front of center, more of the segregation on a truckload to truckload basis comes from the large aggregate particles that collect at the back of the truck. In most cases, therefore, truckload to truckload segregation is more “beginning of the next load” compared to the “end of the first load”.

Figure 8 shows large aggregate particles which have rolled downhill toward the front of the truck bed and collected at that point.

Figure 9 illustrates large aggregate particles which have rolled downhill toward the tailgate of the truck bed and have collected at the back of the truck.
Figure 9: Mix segregation at the tailgate of the truck bed

When the segregated material which comes out of one truck last (at the front bulkhead in the truck) is added to the segregated material which comes out of the next truck first (at the rear tailgate of the truck), truckload to truckload segregation occurs.

In order to completely eliminate the truckload to truckload segregation problem, it is necessary to load the end dump truck correctly. This means that a normal tandem or tri-axle truck needs to be loaded with three drops of mix instead of one. The first drop of mix, as shown in Figure 10, is immediately next to the front bulkhead of the truck bed—as far forward as reasonably possible.

This process will reduce the distance that the coarse aggregate particles can roll to the front of the truck bed and thus significantly reduce the amount of segregation that will occur during the loading operation. Then it is necessary for the truck driver to pull the truck forward so that the second drop of mix can be deposited into the truck bed adjacent to the tailgate on the truck, as shown in Figure 11.
This process will reduce the distance that the coarse aggregate particles can roll to the back tailgate and also significantly reduce the amount of segregation that will occur during the loading operation. The truck driver then needs to move the truck backward so that the third drop of mix can be made into the center of the length of the truck bed, between the first and second drops of mix, as illustrated in Figure 12.

Figure 12: Third drop of mix in the center of the truck bed

Properly loaded, the haul truck will have mix more than half way up the height of the tailgate, as shown in Figure 13.

Figure 13: Mix against the tailgate

If a semi-truck trailer is used to haul the mix to the paver, multiple drops of mix should also be deposited into the length of the truck bed. The first drop of mix should be made as close to the front bulkhead of the bed as possible to reduce the distance that the coarse aggregate can roll. The second drop of mix should be made as close to the tailgate on the truck bed as possible, also to reduce the distance that the coarse aggregate can roll. The remaining weight of the mix should be split, probably into three additional equal portions, and placed throughout the center portion of the length of the truck bed. The key to eliminating the truckload to truckload segregation problem is to keep the first portion of the mix delivered from the truck bed into the paver hopper from being segregated and to also keep the last portion of the mix delivered from the truck bed into the paver hopper from being segregated.
Unloading the Haul Truck:

If the haul truck is loaded properly--using multiple drops of mix into the length of the truck bed with mix against both the front bulkhead and against the rear tailgate--unloading the truck should not create any segregation problems. When the tailgate on the truck is opened, a mass of mix will flow from the truck bed into the paver hopper. As the truck bed is raised, the mix in the truck bed continues to move in a mass. In this case, by loading the truck bed correctly, the largest aggregate particles in the mix will not separate from the rest of the mix. Segregation of the mix will not occur.

If the haul truck is loaded improperly and the large aggregate particles in the mix have rolled both to the tailgate and the front bulkhead on the truck, the segregation problem has already occurred. The problem can be minimized, but probably not completely eliminated, by using a different procedure to unload the haul truck. In this case, the tailgate on the truck bed should remain closed and the truck bed should be raised into the air, as seen in Figure 14.

![Figure 14: Truck bed in the air with the tailgate closed](image)

The bed should be raised far enough for the mix to shift in the bed and move toward the tailgate. This process will add more mix on top of the segregated material at the tailgate. After the mix has shifted, the tailgate can be opened. With the bed up in the air and with the additional mix moved against the tailgate, the combined mix will be moved in a mass into the paver hopper. Some or all of the segregated material will be blended into the rest of the mix and the amount of segregation which will occur behind the paver screed will be significantly reduced. While it is important to unload the haul truck correctly, it is much more important to load the truck bed properly so that the segregation of the mix does not occur in the first place.

CONDITION OF THE PAVER HOPPER BETWEEN TRUCKLOADS OF MIX:

Amount of Mix in the Paver Hopper:

If one is an optimist, the paver hopper should remain half full between truckloads of mix. If one is a pessimist, the paver hopper can remain half empty between truckloads of mix. In either case, the amount of mix which remains in the hopper of the asphalt paver when the truck bed of a haul truck is empty should be above the bottom of the flow gates at the back of the paver hopper or above the opening for the slat conveyors at the back of the hopper if the paver is not equipped with flow gates. Figure 15 shows the correct condition of the paver hopper--half full.
As shown in Figure 16, the paver hopper is essentially empty between truckloads of mix. If segregated material has collected at the tailgate of the haul truck and the tailgate is opened before the bed is raised into the air and the mix in the truck has shifted back toward the tailgate, the first mix that will be dribbled into the empty hopper will be all of the segregated, large aggregate particles that had collected at the tailgate of the truck. With the hopper empty, the segregated material will be pulled through the paver on the slat conveyors and dumped on the augers in front of the screed. This will result in two segregated mix spots behind the screed when the paver moves forward.

![Figure 15: Paver hopper half full between truckloads of mix](image1)

![Figure 16: Paver hopper empty between truckloads of mix](image2)

If the paver hopper is half full, and if there is segregated mix at the tailgate of the haul truck, there is an excellent chance that the segregated material will blend into the mass of mix already in the hopper if there indeed is a mass of mix there. The more mix in the hopper, the greater the chance to “lose” a major portion of the segregated material.

Keeping the hopper half full between truckloads of mix can be easily accomplished by stopping the paver quickly once the haul truck bed is emptied--rapid stop. The haul trucks then should be exchanged with the empty truck pulling out of the hopper and the loaded truck backing into the hopper. Ideally, the bed of the new truck should be partially up into the air and the mix should be made to shift against the closed tailgate. (This is a good practice, even if the haul truck has been loaded properly. It increases the efficiency of the truck exchange and speeds up the unloading process). When the newly arrived truck bed is in the proper position, the tailgate on the truck should be opened. The asphalt concrete mix will then be delivered in a mass into the half full hopper. The paver then returns to its original paver speed quickly--rapid start.

Keeping the hopper half full between truckloads of mix also keeps the head of material--the amount of mix--on the augers in front of the screed constant. This, in turn, keeps the force on the leading edge of the screed constant which, in turn, keeps the angle of attack of the screed constant. This permits the paver to place a smooth mat behind the screed.

If the paver hopper is emptied between truckloads of mix, the segregated mix at the tailgate of the truck will pass directly through the paver hopper and onto the augers. When the paver hopper is empty, the amount of mix on the augers will be significantly reduced. This will reduce the force on the leading edge of the screed and will result in a low spot in the pavement surface. The segregated mix will be deposited on the augers in the low spot in the pavement surface. Truckload to truckload segregation will be created, one very rough textured area on each side of the paver centerline--at the location of the slat conveyors on each side of the machine.
Folding the Hopper Wings:

Coarse aggregate rolls to the sides of the haul truck bed during the truck loading process when the HMA material is delivered from the silo at the asphalt plant. When the truck bed is unloaded, these large aggregate particles move down along the sides of the bed and are carried into the sides of the paver hopper--into the wings. These large particles will then collect in the wings until the wings are emptied.

Emptying the wings in the paver is a major contributing factor to the severity of the segregation that will occur behind the paver screed. If the paver hopper is kept half full between truckloads of mix, as recommended above, mix will be pushed out of the front of the hopper when the wings are raised. Two mounds of mix will be formed in front of the paver. This is shown in Figure 17. This action will directly affect the smoothness of the mat being placed when the paver passes over the top of the two mounds of mix.

![Figure 17: Mix dropped in front of the paver](image)

In order to empty the mix in the wings without dumping mix out the front of the hopper, it is necessary to essentially empty the paver hopper. This is not a good practice. When the wings are folded, the coarse aggregate particles that have collected in the wings are deposited into the bottom of the empty paver hopper. Segregated mix from the tailgate area on the next haul truck will then be added to the segregated mix from the wings. This combined segregated material will then be pulled through the paver on the slat conveyors and deposited on the empty augers. Segregation on the roadway behind the screed will be the result.

In order to keep the hopper half full at all times, it is recommended that the wings on the paver not be raised or emptied. Two different procedures can be used. First, the first mix that flows into the sides of the paver hopper--into the corners of the hopper (into the wings)--at the beginning of the paving process each day can be allowed to remain in the wings all day long. This means that the wings are not raised at any time during the day. The mix that is collected in the corners of the hopper, and remains in the wings all day long, is simply wasted at the end of the day. Depending on the size of the paver, perhaps one to two tons of mix will collect in the wings and be unable to be laid.

Second, and more economically, the capacity of the two corners of the paver hopper can be reduced by fitting the hopper with two fillets, or cutoff plates. This is shown in Figure 18. With the cutoff plates in place, no mix will be collected in the corners of the paver hopper. It is thus not necessary to raise the wings on the paver to get rid of material that was not collected in the first place. With the cutoff plates in place, the paver hopper can be maintained half full at all times. This will greatly reduce any segregation that
might occur. The cutoff plates can be bolted into the sides of the hopper and can be easily removed when necessary.

![Figure 18: Paver hopper equipped with cut off plates in the corner](image)

**Summary of Truckload to Truckload Segregation:**

Truckload to truckload segregation is caused by the manner in which the haul truck is loaded. If the truck bed in loaded in one drop of mix and a conical pile is formed inside the bed, the largest aggregate particles in the mix will roll downhill and collect at the front of the bed, on the sides of the bed, and at the tailgate on the truck bed.

Truckload to truckload segregation can be eliminated by merely loading the haul truck correctly. One drop of mix should be deposited from the surge silo as close to the front bulkhead on the truck bed as possible. The truck driver should then pull the haul truck forward and the next drop of mix deposited as close to the tailgate on the truck bed as possible. The truck should then be backed up and additional drops of mix placed between the first and second amounts of mix. By loading the truck using the proper multiple drop procedure, the distance that the coarse aggregate particles in the mix will be greatly reduced and segregation of the mix will be prevented.

In addition to loading the haul truck correctly, keeping the paver hopper half full between truckloads of mix, practicing rapid stop--rapid start paver operations, and using fillets or cutoff plates in the corners of the paver hopper to eliminate the need to raise or fold the wings will be very beneficial in reducing any amount of segregation that may have occurred during the truck loading process.
TACK COAT

PURPOSE OF A TACK COAT:

The application of a tack coat to an existing pavement surface is a simple, relatively inexpensive process. In fact, it is so simple and cheap that its real importance is often overlooked since it is normally considered to be an incidental expense item in many specifications. Thus the cost of the tack coat material is often not paid for directly, but is included in the cost of other items in the contract. The proper application of the tack coat, however, is critical to the performance of a Hot Mix Asphalt (HMA) pavement structure.

The proper application of an asphalt tack coat can significantly improve the bond between the pavement layers and thus increase the strength of the pavement structure. In addition, the tack coat can reduce the tendency for the surface course layer to slide on the underlying layer under the force of accelerating or decelerating traffic. Finally, the tack coat may reduce the occurrence of top-down cracking in the surface course layers.

A tack coat is normally applied to an existing pavement surface before a new layer of HMA is placed. This is done whether the existing surface is an old asphalt concrete layer or a portland cement concrete (PCC) pavement. In some cases, a tack coat is applied to a new HMA pavement layer before the next layer is placed--such as between a HMA surface course constructed on a HMA leveling course.

Many individuals believe that a tack coat is needed in order to provide a “bond” between an existing pavement surface and a new HMA layer. Some people believe that a tack coat is needed in order to prevent the new HMA layer from sliding on the existing pavement layer. When, and to what extent, bond is formed between layers, however, is the subject of great debate.

Whether the tack coat performs as expected, however, depends on a great number of factors. Among those factors is the type of asphalt material used for the tack coat, such as asphalt emulsion or asphalt binder. Regardless of the type of material used, however, it is not the application rate of the tack coat material that is important, it is the residual amount of asphalt binder remaining on the pavement surface once the tack coat material has “set”.

The proper amount of residual tack coat material on the existing pavement surface normally does not cover the entire surface. In the vast majority of paving situations, the tack coat is distributed over only 90 to 95 percent of the existing surface. This means that 5 to 10 percent of the existing surface is still visible once the tack coat has been applied. Too little tack coat may result in a significant reduction in the strength and durability of the pavement structure. Too much tack coat, however, can easily create a slip plane between the layers and cause the upper pavement layer to slide on the lower layer.
It has often been found, when cores are cut shortly after HMA pavement layers are constructed, that bond between the pavement layers has not occurred. Many variables affect the rate of bond development: climatic factors, the amount of traffic, the thickness of the layers, and the degree of density obtained in the HMA mixture. In some cases, the bond between the new asphalt layer and the old, existing pavement might occur within a few days or weeks. In other cases, however, it could be many weeks or even months before the bond is developed between two layers.

Cores cut from a new overlay, then, may not be immediately bonded to the old pavement surface. It has been found that the bond will develop with time, traffic, and warm weather. The bond will still eventually develop even though only 90 to 95 percent of the existing pavement surface is covered with the tack coat material.

There is no doubt that the application of the tack coat material aids the bond development between the pavement layers and thus the transfer of the traffic loads throughout the thickness of the pavement structure. The tack coat also greatly reduces the amount of sliding or slippage failures that may occur between the existing pavement surface and the new HMA pavement layer. Thus, the proper application of the tack coat is very important in the long term durability of the asphalt concrete pavement.

**SELECTION OF THE ASPHALT MATERIAL:**

In the past, the most widely used type of asphalt material used for a tack coat application was a cutback type material such as RC 800, RC 3000, or MC 3000. Due to environmental concerns, however, cutback asphalts are normally not used for tack coat applications today.

The most common type of asphalt material currently in use for tack coat applications is an asphalt emulsion. A number of different grades of emulsion are used including both rapid set and slow set type materials. For the rapid set emulsions, usually a RS-1, RS-1h, CRS-1 or a CRS-1h material is specified. For the slow set emulsions, the most common grades are SS-1, SS-1h, CSS-1, and CSS-1h. For some high traffic roadway paving projects, the asphalt emulsion may be polymer modified. Detailed information on the properties and characteristics of the various grades of asphalt emulsion can be found in the American Society of Testing and Materials (ASTM) Specification D 997 for emulsified asphalt and D 2397 for cationic emulsified asphalt. Research has shown that the use of a hard base asphalt binder in the emulsion (use of SS-1h in lieu of SS-1) sometimes results in an increase in bond strength and a reduction in the occurrence of sliding failures.

An asphalt emulsion is a combination of asphalt binder (asphalt binder), water, and a very small amount of emulsifying agent (normally less than one percent). Typical asphalt emulsions consist of 55 to 70 percent asphalt binder, depending on the grade of the emulsion. Most grades of asphalt emulsion used for tack coat applications contain approximately 60 to 65 percent asphalt binder. When the water in the emulsion evaporates, it is the residual asphalt content in the emulsion that remains on the pavement surface. For ease of calculation purposes, an asphalt emulsion commonly used for a tack coat application can be taken to be approximately two-thirds asphalt binder (67 percent asphalt binder) and one-third water (33 percent water).

In some areas, asphalt binder is used for the tack coat material instead of asphalt emulsion. In this case, the tack coat material consists of 100 percent asphalt material. The grade of asphalt binder selected typically is the same as incorporated into the HMA mix. For most areas, the asphalt binder tack coat material would meet the requirements of a performance graded (PG) binder—for example, a PG 64-22 or PG 58-28. In some instances, the asphalt binder may be polymer modified.
AMOUNT OF TACK COAT NEEDED:

The amount of tack coat actually needed is a function of a number of factors. It is not correct to apply the same amount of tack coat material to all pavement surfaces regardless of the condition of that surface. Typical residual asphalt application rates and actual application rates are shown in Table 1.

TABLE 1: Typical Application Rates:

<table>
<thead>
<tr>
<th>Existing Pavement Condition</th>
<th>Application Rate (gallons per square yard)</th>
<th>Residual*</th>
<th>Undiluted</th>
<th>Diluted 1:1</th>
</tr>
</thead>
<tbody>
<tr>
<td>New HMA Layers</td>
<td>0.02 - 0.03</td>
<td>0.03 - 0.05</td>
<td>0.06 - 0.09</td>
<td></td>
</tr>
<tr>
<td>Old, Oxidized HMA</td>
<td>0.04 - 0.06</td>
<td>0.06 - 0.09</td>
<td>0.12 - 0.18</td>
<td></td>
</tr>
<tr>
<td>Milled Asphalt Surface</td>
<td>0.05 - 0.07</td>
<td>0.08 - 0.11</td>
<td>0.15 - 0.21</td>
<td></td>
</tr>
<tr>
<td>Milled PCC Surface</td>
<td>0.05 - 0.07</td>
<td>0.08 - 0.11</td>
<td>0.15 - 0.21</td>
<td></td>
</tr>
<tr>
<td>Portland Cement Concrete</td>
<td>0.04 - 0.06</td>
<td>0.06 - 0.09</td>
<td>0.12 - 0.18</td>
<td></td>
</tr>
</tbody>
</table>

* Also the application rate for asphalt binder

The primary factor to be considered is the existing pavement surface condition. If that surface is clean and smooth, a minimum of tack coat is normally needed. This is due to the fact that little tack material will be absorbed into existing surface and minimal tack material will be needed to offset the dust on the surface. For a clean, tight surface, the residual amount of tack coat required will generally be in the range of 0.03 to 0.05 gallons per square yard (g/sy).

If the exiting pavement surface is aged and oxidized, the residual amount of tack coat applied should be increased slightly to compensate for any material that might be absorbed into the old surface. Further, if the existing pavement surface contains many hairline cracks, the residual amount of the tack coat material should also be increased slightly. For an aged, oxidized existing surface, the residual amount of tack coat required will generally be in the range of 0.04 to 0.06 g/sy.

If a new leveling course has been placed over the underlying asphalt or concrete pavement surface, it may not be necessary to apply a tack coat on the new leveling course. If, for example, an HMA leveling course is placed on Monday and the HMA surface course is placed over the leveling course the same day or on Tuesday, a tack coat typically is not needed. If the leveling course layer is clean and smooth, there will be minimal absorption of the tack coat material. If, however, the leveling course has gotten dirty between the time of its placement and the time of the placement of the next HMA course, the pavement surface should be cleaned and a minimum amount of tack coat applied. In the latter case, the residual amount of tack coat material should be in the range of 0.02 to 0.03 g/sy.

Some recent research has found that the application of a tack coat between new layers of HMA is beneficial in reducing the occurrence of top-down cracking in the new layers. In addition, tack coat between new layers of HMA should be required in locations of accelerating or decelerating traffic, turning areas, steep grades, high volumes of traffic, very hot climates, and between relatively thin layers of HMA.

In the case where the original pavement surface, either HMA or PCC has been milled, the tack coat application rate should be increased to compensate for the dust from the milling operation and the increase in the surface area and surface texture of the milled surface. Even though the milled surface has been cleaned by brooming or flushing with high pressure water, some dust, dirt, and debris may remain in the bottom of the milling grooves. For this type of construction operation, the residual amount of tack coat material should be in the range of 0.05 to 0.08 g/sy. Some individuals believe that a tack coat does not need to be applied to a milled pavement since the rough, milled surface will prevent the new pavement layers
from sliding. It is strongly suggested, however, that a tack coat should be applied to the milled surface to help achieve a bond between the new and the old pavement layers.

Finally, if the pavement layer being resurfaced is portland cement concrete, it might be necessary to slightly increase or decrease the residual tack coat amount depending on the texture of the PCC surface. A relatively smooth surface texture will require less tack coat and a relatively rough surface texture will require more tack coat. The residual amount of tack coat required will generally be in the range of 0.04 to 0.06 g/sy.

A secondary consideration is the type of terrain where the pavement is located. If the grade is relatively flat, the residual tack coat application rates given above are typically adequate. However, if the roadway being paved is located in a hilly or mountainous area, it might be prudent to reduce the amount of tack coat. Lowering the residual tack coat rate by 0.01 g/sy or keeping the application rate at the lower side of the suggested range would be recommended. It is very important to note that excessive tack coat on the pavement surface in mountainous terrain might cause problems with slippage of the haul trucks and the paver in the tack coat when moving up or down hill and slippage of the completed pavement course at the interface between the layers. The reduction in the rate of the tack coat application due to the above construction considerations in hilly terrain is offset, however, by possible reduced performance of the pavement layers due to the high shear stresses caused by traffic moving uphill or downhill.

Another secondary factor is the environmental conditions at the time of paving. If an asphalt emulsion is used for the tack coat, and if the humidity is very high or the ambient temperature is very high, the emulsion setting and curing time will be extended. The same is true if the pavement surface is damp from rain. Reducing the residual amount of tack coat by 0.01 g/sy or keeping the application rate at the lower side of the suggested range would again be prudent. A change in the type of tack coat material used, from a soft asphalt emulsion to a hard asphalt emulsion (SS-1 to SS-1h, for example) should be considered. A change from an asphalt emulsion to an asphalt binder might also be feasible.

**CALCULATION OF THE APPLICATION RATE:**

To determine the application rate for an asphalt emulsion tack coat, it is absolutely necessary to start with the residual asphalt content--the amount of asphalt binder remaining on the pavement surface once the water in the emulsion evaporates. If, for example, it has been determined that a residual asphalt content of 0.04 gallons per square yard (g/sy) is needed, an application rate of 0.06 gallons per square yard should be delivered from the asphalt distributor. This calculation is based on a ratio of two-thirds residual asphalt binder and one-third water in the asphalt emulsion and is done by multiplying the residual asphalt content by a factor of 1.5 to determine the required application rate.

If the residual asphalt content of the asphalt emulsion was required to be 0.06 g/sy, for example, the emulsion application rate from the distributor would be approximately 1.5 times as great, or 0.09 g/sy (0.06 x 1.5 = 0.09). Similarly, if the required residual asphalt content was 0.05 g/sy, the application rate from the distributor would be 1.5 times as great, or 0.075 gallons per square yard.

In some cases, it is advantageous to dilute an asphalt emulsion in order to achieve a more uniform application of the residual asphalt binder in the emulsion on the pavement surface. The usual dilution ratio is 1:1. Thus, one part water is added to one part emulsion. This means that the original emulsion makes up only 50 percent of the diluted emulsion. It also means that only one-third of the diluted emulsion will actually be residual asphalt binder--two thirds will now consist of water. The water used to dilute the emulsion must be potable--suitable for drinking.
It is noted that only slow setting emulsions can be diluted with water. When a slow set emulsion is diluted, the water is added to the emulsion—not the emulsion to the water. Adding the emulsion to the water may cause the emulsion to break and cause water and the asphalt binder to separate. It is noted that a diluted emulsion will typically take longer to set than will an undiluted emulsion under the same environmental conditions, thus possibly delaying the placement of the HMA mix.

For an emulsion that is diluted 1:1 with additional water, for a required residual asphalt content of 0.04 g/sy, it would be necessary to apply the diluted asphalt emulsion at a rate of 0.12 g/sy from the asphalt distributor. This application rate is calculated by multiplying the residual asphalt content by a factor of 3.0 to determine the required application rate of the 1:1 diluted emulsion.

If the residual asphalt content was required to be 0.06 g/sy, for example, the application rate of the diluted emulsion would be approximately 3.0 times as great, or 0.18 g/sy (0.06 x 3.0 = 0.18). Similarly, if the required residual asphalt content was 0.05 g/sy, the application rate of the diluted emulsion from the distributor would be 3.0 times as much, or 0.15 gallons per square yard.

It is very important to note that it is the residual asphalt content in the emulsion that is the key to the tack coat performance. If a distributor operator applies an undiluted asphalt emulsion tack coat at rate of 0.10 g/sy, the amount of residual asphalt will be approximately 0.066 g/sy. If a distributor operator applies an asphalt emulsion that has been diluted 1:1 with water at the same application rate, 0.10 g/sy, however, the amount of residual asphalt will be only 0.033 g/sy. This reduced residual amount most likely will not provide adequate performance. The application rate of the tack coat should always be calculated by starting with the required residual rate and working backward to determine the application rate.

The distributor operator must know if the asphalt emulsion material has been diluted or not. In addition, he or she must know what the residual asphalt content is supposed to be and then back-calculate to determine the application rate of the emulsion from the distributor. Unfortunately, many distributor operators simply do not know whether the emulsion has been diluted or not or know how to determine the application rate and/or the residual rate for the tack coat material. If pure asphalt binder is used for the tack coat, the application rate from the distributor spray bar and the residual rate on the pavement surface will be exactly the same.

APPLICATION EQUIPMENT:

Asphalt Application Temperature:

Proper tack coat application begins with the asphalt distributor (shown in Figure 1) used to deliver the tack coat material to the existing pavement surface. The tack coat material in the distributor tank must be kept at the proper temperature to assure that the material can be sprayed uniformly onto the existing pavement surface. When an asphalt emulsion is used, it should normally be applied at a temperature between 120°F and 160°F. When an asphalt binder is used, it should normally be applied at a temperature between 275°F and 325°F. It is very important to have the tack coat material at the proper application temperature in order to obtain a uniform distribution on the existing pavement surface.
Spray Bar Nozzle Size:

Uniform tack coat application also depends on the size of the nozzles used on the distributor spray bar. If asphalt binder is used and the application rate (and residual amount) is only 0.04 gallons per square yard, for example, the nozzle size used should be appropriate to uniformly apply that amount of material. If a 1:1 diluted asphalt emulsion is used and the application rate is 0.18 g/sy (for a residual amount of 0.06 g/sy), it will generally be necessary to use larger nozzles on the spray bar to achieve the desired tack coat uniformity.

It is noted that the nozzle size needed to apply an asphalt emulsion for a surface treatment, chip seal, or seal coat is significantly larger than the nozzle size required to apply an asphalt emulsion for a tack coat. For a surface treatment which requires a residual asphalt content of 0.28 g/sy to properly hold the cover aggregate, the application rate for an undiluted emulsion would be 0.42 g/sy. Compare that application rate to that of an undiluted asphalt emulsion rate of 0.06 g/sy for a tack coat with a residual asphalt content of 0.04 g/sy. Obviously the same size nozzles cannot be used for both types of application.

A chart usually supplied with each distributor provides the operator with information on the proper nozzle size to use for different application rates. In too many cases, the same distributor used for surface treatment construction is used to apply the tack coat material during a HMA paving operation. If the nozzles are not changed, the asphalt tack coat application will be extremely non-uniform—the asphalt material will come out in longitudinal streaks instead of a fan-like spray. It is noted that the pump pressure on the distributor must be set to match the desired application rate of the tack coat.

Spray Bar Operation:

Once the correct nozzle size is selected for the desired application rate and the type of tack coat material being applied, the next step is to assure that all of the nozzles on the spray bar are set at the correct angle and are functioning properly. This means that the nozzle opening (slot) should be set at an angle of approximately 30 degrees to the axis of the spray bar. If all of the nozzles are not set at the same angle, non-uniform application of the tack coat will result. In addition, all the nozzles must be working correctly. If a nozzle(s) is partially or completely blocked, non-uniform application of the tack coat material will result.

For a tack coat application, a double or triple lap of the asphalt material from the spray bar to the road surface can be used. The amount of overlap will depend on the height of the spray bar above the
pavement. In most cases, a triple lap is used even though it is not necessary to completely cover the existing pavement surface with the tack coat—90 to 95 percent coverage is typically adequate.

As the tack coat material in the tank on the distributor is used, the height of the spray bar may rise slightly, changing the amount of nozzle overlap. To compensate for this problem, most modern distributors are equipped with a system to maintain a constant bar height regardless of the amount of material in the distributor tank. If the distributor being used is not so equipped, the height of the spray bar must be manually adjusted to compensate for the change in the height of the bar as the distributor is emptied.

The forward travel speed of the distributor must be controlled to assure that the application rate is correct. If the distributor travels too fast, the amount of tack coat applied to the pavement surface will be reduced. The opposite effect occurs if the distributor travels too slowly for a given spray bar nozzle size and pump pressure.

**Trial Tack Coat Application:**

Before the tack coat application starts, the distributor operator should check the temperature of the asphalt material to assure that it is at the correct spraying temperature for the type of material being used. In addition, the nozzles on the spray bar should be checked to assure that they are of the proper size and that they are all turned to the same angle to the axis of the bar.

If the distributor has not been used for time, it is good practice to construct a trial placement of the tack coat over some convenient, unused area to assure that all the nozzles are operating properly. In addition, the trial run can be used to judge the tack coat application uniformity as well as confirm that the proper amount of tack coat application. If desired, the distributor application rate can be calibrated, both in a transverse direction and in a longitudinal direction, in accordance with ASTM D 2995. This is shown in Figure 2.

![Figure 2: Calibration of an Asphalt Distributor Application Rate](image)

**PREPARATION OF THE EXISTING PAVEMENT SURFACE:**

If the existing pavement surface is dusty, the application of the tack coat may not provide adequate bond between the pavement layers or prevent sliding of the new layer on the old layer. Thus it is extremely important to thoroughly clean the existing surface before the tack coat is applied. This should be accomplished by properly sweeping and/or flushing the existing pavement surface with high pressure water to remove any dust film before placing the new HMA material.
TACK COAT APPLICATION:

Proper and Improper Tack Coat Application:

Figure 3 illustrates the proper tack coat application. First, all of the nozzles on the distributor spray bar are functioning properly. All of the nozzles are set at the same angle to the axis of the spray bar. The tack coat is being applied uniformly from all of the nozzles. In addition, the amount of tack coat being sprayed appears to be correct since a small portion of the pavement surface is still visible—only 90 to 95 percent of the existing pavement surface is covered with tack coat material.

Figure 3: Uniform Application of the Tack Coat

Figure 4 depicts two examples of improper tack coat application. In this case, several of the nozzles on the distributor spray bar are clogged or are only spraying a partial amount of material. A number of the nozzles are also set at incorrect angles to the bar. This non-uniform tack coat application will not provide consistent bond between the pavement layers.

Figure 4: Very Non-Uniform Application of the Tack Coat
Figure 5 shows the excessive tack coat application to an existing PCC pavement surface. This amount of tack coat will merely create a slip plane between the concrete pavement surface and the new HMA layer and should be avoided at all times.

Figure 6 illustrates the difference in the application rate for an undiluted asphalt emulsion sprayed by the same asphalt distributor as shown in Figure 5. The equipment is the same--only the application rate has been varied. Again, it is recommended that 90 to 95 percent of the existing pavement surface be covered with tack coat. At top of the picture, the application rate is too heavy. At the bottom of the picture, the tack coat application rate is about right.

In summary, when the tack coat material is being applied to the pavement, it is important to observe the following items: (1) all of the nozzles on the spray bar should be open and fully functioning; (2) all of the nozzles on the spray bar should be set at the same angle to the axis of the bar and all of the fans should be in the same direction; (3) the height of the spray bar above the ground should provide for a double or triple overlap of the fans; and (4) the tack coat should cover approximately 90 to 95 percent of the pavement surface.

Tack Coat Break Time:

If asphalt binder or polymer modified asphalt binder is used as a tack coat, there is no break time involved. When the asphalt binder is applied to the pavement surface, it will cool to ambient temperature, usually within a minute or two. Once that has occurred, the new HMA mix can be placed on top of the tack coat.

When an asphalt emulsion is used, the color of the emulsion, when it is delivered from the spray bar, is brown. This means that the asphalt binder particles are still suspended in the water portion of the emulsion. When the color of the tack coat changes from brown to black, the emulsion has “broken”, and the asphalt binder has separated from the water. The two phases of the emulsion are still present, however. Depending on the emulsion application rate, the dilution rate, and the environmental conditions, it might take as little as five minutes or as long as twenty minutes or more for the emulsion to break.

Before the emulsion breaks, the tack coat can normally be driven on by the haul trucks or with the paver wheels or tracks with minimum pickup of the emulsified material. This is because the emulsion is still very liquid and not yet sticky. There is generally no problem with placing asphalt concrete mix over an
unbroken emulsion. The amount of water in the emulsion, even a diluted emulsion, is minimal and will not affect the bond of the new layer to the existing pavement surface.

In some parts of Europe, a separate distributor is not used to apply the tack coat. An emulsion tank is placed on the paver and the spray bar is located about one foot in front of the head of HMA material in front of the paver screed. Because of the spray bar location, there is no time for the emulsion to break before the new hot mix asphalt is deposited on top of it. Also due to the location of the spray bar, no vehicle tires or paver wheels or tracks come in contact with the tack coat material and pick up the tack coat. In Europe there have been no problems with this method of paving over the unbroken tack coat material.

**Tack Coat Set Times:**

As discussed above, if a pure asphalt binder is used as a tack coat material, there is no set time involved with the material. Once the material cools to the same temperature as the existing pavement surface--a matter of minutes--it is ready to have the HMA mix placed on it.

As discussed above, when an asphalt emulsion breaks, the asphalt binder particles have separated from the water. Once the water completely evaporates, the emulsion has “set”. Once the emulsion has set, it is ready to have the HMA mix placed on it. Depending on the application rate of the emulsion, the dilution rate, and the environmental conditions, it might take as little as fifteen minutes for the emulsion to set or as long as two hours for that to occur.

Between the tack coat emulsion break time and set time, the tack coat is very sticky and will adhere to the haul trucks tires and be carried off of the existing pavement surface. This situation obviously defeats the purpose of applying the tack coat in the first place. Figure 7 shows two examples of the removal of the tack coat from in front of the paver by the tires of the haul vehicles.

![Figure 7: Pickup of the Tack Coat on the Tires of the Haul Trucks](image)

As mentioned above, pick up of the tack coat on the haul truck tires can be minimized by driving over the asphalt emulsion before it has broken. If this is not desirable, then the only other means to prevent the tack coat pick up problem is to assure that it is completely set prior to the haul trucks driving over the material. Depending on the factors described above, the delay obtaining the set time for the emulsion can significantly delay the placement of the asphalt concrete mix. If HMA placement is not delayed, the tack coat will be removed from the existing pavement surface by the tires of the haul trucks and the tack coat
obviously will be completely ineffective in creating the necessary bond between the new and old HMA layers. In addition, if the tack coat material is picked up on the tires of the haul trucks, it can be deposited on adjacent pavement surfaces.

Reducing the Pick Up Problem:

The pick up problem can be significantly reduced by using the following techniques: (1) minimizing the tack coat residual application rate; (2) assuring uniform tack coat application across the pavement width by using the proper nozzle size, nozzle angle, and spray bar height; (3) using an asphalt binder for the tack coat; and (4) applying the tack coat as far ahead of the paver as feasible (depending on traffic safety requirements).

Research has shown, however, that a tack coat material on the pavement surface can significantly reduce the level of friction available to a vehicle tire, particularly if the pavement surface is wet. Thus placing the tack coat out ahead of the paver must be done with caution. If rain is eminent, the amount of tack coat placed ahead should be controlled. If the tack coat is exposed to traffic, consideration should be given to applying a light layer of sand to the tack coat.

Pick up can also be reduced by paving over an emulsified asphalt tack coat while it is unbroken--still brown in color. Although this procedure is not normal practice in the United States, it has been very effective in Europe.

MAINTENANCE OF TRAFFIC:

For safety reasons, public traffic should be restricted from traveling over the tack coat material at all times. If traffic must travel over the tack coat material at locations such as intersections, it is suggested that a light application of sand be placed on top of the tack coat in these areas. The sand can be applied at a rate of 4 to 6 pounds per square yard. The use of the sand cover will reduce the pick up that might occur and also improve the pavement surface friction.

SUMMARY:

The main purpose of a tack coat is to provide a bond between the existing pavement surface and a new layer of Hot Mix Asphalt and to reduce the possibility of a sliding failure between the new and old pavement layers. To accomplish these purposes, however, it is not necessary for the tack coat material to completely cover the underlying pavement surface. Only 90 to 95 percent of the area needs to be covered to achieve adequate bond. In addition, both too little tack coat as well as too much tack coat is detrimental to the long term performance of the HMA pavement structure.

The residual amount of asphalt binder is of primary importance for a tack coat. The residual asphalt content should be based on the type and condition of the existing pavement surface, the type of terrain where the roadway is located, and the existing environmental conditions. The application rate for the tack coat will also depend on the type of material used--asphalt emulsion or asphalt binder--and whether the asphalt emulsion is diluted.

The asphalt distributor must apply the tack coat material uniformly to the existing pavement surface. The spraying temperature of the material must be proper for the type of asphalt material being used. In addition, the proper nozzle size should be used, the angle of the nozzles must be about 30 degrees to the axis of the spray bar, and the height of the spray bar above the pavement surface should provide for a double or triple lap of the fans from the nozzles. Finally, all of the nozzles should be open and functioning properly.
Tack coat material that has not completely set is very sticky. It will adhere to the haul truck tires and be carried off of the paving lane. Once the tack coat material is picked up and removed, it is obviously not able to serve its intended purpose. Thus every effort must be made to eliminate the movement of the haul trucks, or public traffic, over the tack coat material before it sets.

The proper, uniform application of the asphalt tack coat contributes significantly to the long term durability of the new Hot Mix Asphalt pavement layers.
YIELD--THICKNESS--SMOOTHNESS

Many contractors are faced with a very difficult decision--how to achieve yield, thickness, and smoothness at the same time. Unfortunately, it generally can not be done.

The way a typical asphalt paver works has not changed since 1931 when the free-floating screed principle was introduced by the Barber-Greene Company. As everyone knows, the primary purpose of the paver is to level--to place more HMA mix in the low spots on the existing pavement surface and less mix on the high spots. For this reason, the amount of mix needed to resurface a state highway, county road, city street, or parking lot depends on the smoothness of the existing pavement surface.

Yield: In most cases the amount of mix needed to resurface a pavement is determined from a calculation of length times width times thickness, converted to a tonnage value. If the pavement is “out of shape”, the designer may add 2 to 4 percent more mix to allow for the depressions in the surface. Most pavements, however, require 5 to 15 percent more material so that proper smoothness can be obtained.

In order to place a minimum thickness of mix on the high spots in the existing pavement surface, it is necessary to increase the thickness of the mix in the low spots. This situation results in the need for additional mix beyond what is normally calculated based on length, width, and thickness numbers. The contractor must be provided with enough mix to properly construct the pavement. In many instances, the amount of funds available to resurface the pavement is limited and thus the amount of mix included in the contract is also, incorrectly, minimized.

Thickness: Suppose the plans call for a surface course mix that is 1-1/2 inches thick. If the inspector on a paving project takes that to be a minimum thickness everywhere, there is going to be a problem with yield. Again, depending on the smoothness of the existing pavement surface, it is going to take “extra” mix to fill in the low spots. Thus to achieve a minimum thickness on the high spots, the thickness of the mix in the low spots must be greater than the minimum.

The thickness shown on the plans thus becomes an average thickness instead of a minimum thickness. If this is not done, the contractor will run out of mix before he runs out of roadway. Either that or his mix tonnage will significantly increase over the amount shown in the plans. This, of course, creates a problem with yield.

Smoothness: The amount of smoothness obtained depends on two major factors. The first is the condition or smoothness of the existing pavement surface. The second is the number of layers of HMA mix that is to be placed on top of that existing surface.
Based on the free-floating screed principle, each layer of HMA mix improves the smoothness of the underlying pavement layer by a significant amount. If the present pavement surface is relatively smooth, any new layer placed will be smoother than the original surface since the paver will add more HMA mix in the low spots and thus level that original surface. If the existing pavement surface is rough and uneven, however, the surface of the new layer will be smoother than the original surface, but will still be rough to some extent. This is due to differential compaction.

A layer of dense graded HMA mix will typically compact 1/4 inch per inch of compacted thickness. That means that a layer of mix that is 1 inch thick, when compacted, must be placed 1-1/4 inches thick by the paver in order to allow for the densification that is going to occur under the compactive effort applied by the rollers. A HMA layer that is compacted to a 2 inch thickness needs to be placed 2-1/2 inches thick in order to achieve the proper amount of density. When mix is placed along a roadway in variable thicknesses, due to the condition of the existing pavement surface, the compacted new surface will still not be completely smooth since the thick areas of mix will compact more than the thinner areas.

A second layer of mix will make the surface of that second layer smoother than the original pavement surface. This is because the amount of differential compaction between the thicker and thinner areas will be reduced. The placement of a third layer will make the new surface even smoother. The greater the number of layers constructed, the smoother the final pavement surface. The final smoothness is still dependent, however, on the smoothness of the original pavement surface.

Yield, Thickness, and Smoothness: There are three basis rules in the asphalt paving industry in regard to the resurfacing of an existing pavement surface.

First, if yield is the primary consideration, the paver screed operator will have to continually adjust the angle of attack of the screed in order to reduce the amount of mix placed over the present pavement surface. This, of course, will affect both the minimum thickness of the mix over the high spots in the existing surface and the smoothness of the new pavement layer. The amount of mix set up in the contract must be enough to allow the contractor to properly level the existing pavement surface.

Second, if a minimum thickness of mix over the high spots in the existing surface is required, then the amount of mix needed will increase over the quantity shown on the plans. This will result in an increase in the cost to complete the project but will result in a smoother pavement surface. A minimum layer thickness can result in a very rough ride.

Last, if smoothness is a primary consideration, several things must happen. First, the number of layers of mix placed must be increased--only one layer will not do the job, even if a “scratch course” of mix is placed. Second, enough quantity of mix must be available to properly level the surface--fill in the low spots and “shave off” the high spots. Third, the paver screed operator must allow the paver to do its job without continually adjusting the angle of attack of the screed.

Yield, minimum thickness, and smoothness can not be obtained at the same time unless enough mix and number of pavement layers are set up for the project for the contractor to let the paver screed do its job--fill in the low spots and improve the smoothness of the pavement surface, one layer at a time.
COMPACtion of
STIFF and TENDER
ASPHALT CONCRETE MIXES

James A. Scherocman, P.E.
Consulting Engineer
11205 Brookbridge Drive
Cincinnati, Ohio 45249

513-489-3338
jim@scherocman.com

Revised September 1, 2008
INTRODUCTION:

It has often been said that the degree of compaction of a hot mix asphalt (HMA) concrete mixture is the single most important factor that affects the ultimate performance of the pavement under traffic. Compacting an asphalt concrete mixture to an air void content of six percent or less generally increases the fatigue life, decreases the amount of permanent deformation or rutting, reduces the amount of oxidation or aging, decreases moisture damage or stripping, increases strength and internal stability, and may even decrease slightly the amount of low temperature cracking that may occur in the mix.

A HMA mixture may have all the desired mix characteristics and properties when designed in the laboratory. That same mix, however, may perform poorly under traffic if that mix is not compacted to the proper level of density on the roadway. A mix that may have only marginal properties in the laboratory will often outperform a mix with more desirable properties if the marginal mix is adequately and properly compacted.

Compaction is the process through which the asphalt mix is compressed and reduced in volume. Compaction permits the unit weight or density of the mix to be increased by placing more material into a given volume or space or by taking a given amount of material and compressing it into a smaller space or volume. As a result of the compaction process, the asphalt coated aggregate particles in the mix are forced closer together, which increases the amount of aggregate interlock and interparticle friction and also reduces the air void content of the mix.

With the advent of the Superpave mix design method in the United States, problems have been experienced in obtaining the desired degree of compaction in some of the mixtures. In a few cases, the problems have been related to the increased stiffness of the HMA material due to the incorporation of a polymer modified binder into the mix. In most cases, however, the problems have been related to a lack of internal stability in the HMA material and the presence of a "tender zone" experienced at some point during the compaction process. Within the temperature range at which the tender zone exists, the mix moves under the applied compactive effort of the rollers and thus it is normally very difficult to achieve the required level of density.

The purpose of this paper is to review some of the possible causes for both stiff and tender asphalt concrete mixtures and to discuss how to properly compact each type of mix. For mixtures which exhibit tender characteristics, the contractor must be aware of the three temperature zones which typically exist during the rolling process.

SUPERPAVE MIXTURE PROPERTIES:

Traffic Levels:

The Superpave mix design procedure is based on the amount of traffic that will be travelling over the HMA pavement. The most recent revision of the Superpave system divides the mix design criteria into five different traffic categories. Those categories are based on the number of equivalent single axle loads (ESALs) that will be pass over the pavement structure during a twenty year design period. The traffic levels used are <0.3, 0.3 to 3, 3 to 10, 10 to 30, and >30 million ESALs.

Aggregate Properties:

The minimum required aggregate properties change depending on the level of traffic. The angularity of the coarse aggregate particles is measured in terms of fractured faces--both one and two fractured faces. As the amount of traffic increases, the minimum one and two face crushed content of the coarse aggregate also increases. The minimum fractured face count, however, is also dependent on the
location of the layer within the pavement structure--less than or more than 100 mm below the surface of the HMA.

The minimum angularity level of the fine aggregate particles also increases as the number of ESALs increases and is related to the depth of the HMA layer beneath the pavement surface. As the amount of traffic loading increases, the fine aggregate angularity level also increases. In addition, the sand equivalent value for the mixture also increases as the number of ESALs applied to the pavement increases. The number of flat and elongated aggregate pieces in the HMA mix is also regulated, based on a 5:1 maximum to minimum ratio. This ratio, however, is not affected by traffic category.

The gradation limits for the combined coarse and fine aggregate are based on the nominal maximum size of the aggregate, defined as the next sieve size larger than the first sieve to retain more than ten percent of the aggregate. As the nominal maximum size of the aggregate used in the mix decreases, the minimum voids in mineral aggregate (VMA) percentage in the HMA increases.

The purpose of the aggregate consensus properties is to provide a mixture which is stiffer and more resistant to both fatigue damage and permanent deformation. In essence, as the amount of traffic increases, the amount of uncrushed natural sand that can be added to the mix decreases and the coarse aggregate must be more angular in order to create more interlock between the aggregate particles. Thus, for high traffic loads, a HMA mix design using the Superpave aggregate criteria should produce a relatively stable, stiff asphalt concrete mixture. Such a mixture should be more difficult to compact to a given air void content.

Binder Properties:

The Superpave system has created a whole new method of characterizing asphalt cement binder materials. The Performance Grading (PG) system bases the minimum requirements for the binder on the average seven day maximum pavement temperature and on the minimum temperature to which the pavement will be subjected. Depending on the location of the pavement, the binder may or may not be modified in order to meet the minimum performance criteria.

For many lower traffic volume roadways, an unmodified asphalt cement is typically specified for use in the HMA. As the number of ESALs applied to the pavement increases, however, it is often necessary to modify the binder material with some type of polymer in order to obtain the desired binder properties. In addition, as the range between the minimum and maximum ambient temperatures increases, the use of modified binder materials also increases.

The purpose of the PG grading system is to provide a stiffer binder for increased levels of traffic and for harsher environmental conditions. A HMA mix that incorporates a stiff binder material will normally be more difficult to compact to a given air void content.

Aggregate Gradation Requirements:

For each particular HMA mix, based on the nominal maximum size of the aggregate incorporated into the mix, there are control points applied to the combined coarse and fine aggregate gradation. The control points limit the maximum and minimum amount of aggregate that can pass a particular sieve. In addition, there are maximum and minimum amounts of aggregate that can pass the 0.075 mm (No. 200) sieve for each nominal maximum aggregate size mix.

The purpose of the aggregate gradation requirements is to increase the stiffness of the asphalt concrete mix. Extreme combinations of coarse and fine aggregate are eliminated and, theoretically,
mixtures that are very densely graded--parallel the so-called maximum density line--can not pass the specifications. Such mixtures will be more difficult to compact to a given air void content.

**Laboratory Compaction Parameters:**

The Superpave design system includes the use of a gyratory compactor to produce HMA mix specimens for laboratory testing. Three levels of compactive effort are required, based upon the number of revolutions applied. Those revolutions were originally labeled n-initial, n-design, and n-maximum. The use of the n-maximum criteria has been eliminated and Superpave designed mixtures are currently compacted to the n-design number of gyrations. As the number of ESAL's applied to the pavement increases, the minimum number of revolutions of the gyratory compactor also increases.

On a practical basis, as the number of ESALs becomes greater and the n-design value also increases, the amount of binder added to the mix decreases. Everything else being equal, a HMA mix which contains less binder material should be more difficult to compact to a given air void content.

**COMPACTION OF STIFF HMA MIXTURES:**

Particularly for high volumes of traffic, a properly designed Superpave mix should result in an asphalt concrete mixture which is relatively stiff and relatively difficult to compact. For such mixtures, the compactive effort applied to the mix on the roadway must be accomplished while the temperature of the HMA material is still high. A variety of compaction equipment can be used in various combinations, including double drum vibratory rollers, pneumatic tire rollers, and static steel wheel rollers, to accomplish the task.

For unmodified HMA, the typical mix laydown temperature (the temperature of the mix passing out from under the paver screed) is in the range of 150° C to 135° C (300° F to 275° F). For a polymer modified HMA material, the typical mix laydown temperature is in the range of 160° C to 140° C (320° F to 285° F), depending on the type of polymer used in the mix.

Most specifications require a minimum level of density be obtained in the mix. That minimum level is typically set at 92 percent of the theoretical maximum density (TMD) of the HMA mix--a maximum air void content of 8 percent. For some coarse graded Superpave mixtures--those with gradations below the so-called maximum density line--some state highway departments have specified the minimum density level at 93 percent of the TMD value. This increase in the minimum density level is in response to problems with high water permeability in some of the coarse graded HMA mixtures.

**Conventional Roller Combinations:**

Two primary groups of "roller trains" have been employed in recent years to compact stiff HMA mixes. The most popular combination consists of a double drum steel wheel vibratory roller operated in the initial or breakdown position. This roller is followed by a pneumatic tire roller operated in the intermediate or second position. Finish or final rolling is typically completed by a static steel wheel roller.

The double drum vibratory roller is usually kept relatively close behind the paver to obtain the initial compactive effort while the mix is still hot. In general, the breakdown rolling should be completed before the surface temperature of the mix falls below 120° C (250° F). The roller is operated at the highest possible frequency level available for the particular make and model of roller and at an amplitude setting that is dependent on the thickness of the asphalt concrete mat being placed. For HMA layers less than 30 mm (1-1/4 in) thick, the vibratory roller should not be operated in the vibratory mode--the roller should be run in the static mode to avoid fracturing the aggregate in the mix. For HMA layers ranging in
thickness from 30 mm to about 75 mm (1-1/4 to 3 in), a low amplitude setting is used on the vibratory roller. For greater thicknesses of asphalt concrete mix, a higher amplitude setting can be used without fracturing the aggregate in the mix.

When a pneumatic tire roller is used as an intermediate roller, it is usually necessary to keep the tires at the same temperature as the mat being compacted. This means that the roller can not be allowed to sit and wait for long periods of time, allowing the temperature of the roller tires to decrease to the point that pickup of the mix is experienced. For some polymer modified HMA mixes, it may be very difficult to prevent pickup depending on the type and concentration of polymer used in the mix. Intermediate rolling should be completed, for a relatively stiff Superpave mix, before the surface of the mix reaches a temperature of approximately 100° C (210° F). The intermediate roller thus should be kept directly behind the breakdown roller.

A static steel wheel roller is usually used for finish rolling. The primary purpose of this compactive effort is to obtain the “last little bit” of density and to remove the marks, if any, left by the first and second rollers. For stiff Superpave designed mixes, finish rolling should be accomplished before the surface temperature falls below about 80° C (175° F).

Alternative Roller Combinations:

For Superpave mixtures that contain high levels of polymer and are very stiff even at relatively high laydown temperatures (above 160° C or 320° F), one alternative combination of rollers that has often been used to obtain the required level of density consists of a pneumatic tire roller in the breakdown or initial position behind the paver. In this case, the pneumatic tire compactor is kept as close to the paver as reasonably possible. As in the case discussed above where the pneumatic tire roller is used in the intermediate position, the tires of the roller must be kept hot—the same temperature as the mix being compacted.

Before starting compaction at the beginning of the day, it is necessary to run the pneumatic tire roller back and forth for on a previously placed pavement for a period of ten to fifteen minutes in order to build up heat in the tires. For most normal binder (unmodified) mixtures, the pneumatic tire roller can then be operated on the new mat directly behind the paver after mix placement starts. For some polymer modified mixtures, however, it may be necessary to put the pneumatic tire roller on the mix behind a double drum vibratory roller for a few minutes in order to allow the temperature of the tires to fully reach the temperature of the mix. Once that has been achieved, the pneumatic tire roller can be moved into the breakdown position ahead of the double drum vibratory roller. It is noted that the pneumatic tire roller should be operated without water being sprayed onto the tires.

The second roller should be a double drum vibratory roller, operated close behind the pneumatic tire roller. The frequency of vibration used for this roller should be as high as possible. The amplitude setting, however, should be related to the thickness of the mat being placed, the same as when this type of roller is used in the breakdown position. This roller pattern—a pneumatic tire roller in the breakdown position with a vibratory roller in the second position—is shown in Figure 1.
For this combination of rollers, it is often not necessary to use a static steel wheel finish roller. The tire marks left by the pneumatic tire roller are readily removed by the vibratory roller. This is due to the fact that the latter machine operates on the mat when the temperature of the mix is higher compared to the temperature of the mix under the static finish roller behind the pneumatic tire roller in the conventional roller train. In addition, the smooth steel wheel drums of the vibratory roller typically leave few, if any, marks in the mat when this roller is used behind the pneumatic tire roller. If marks are present, they can usually be erased easily by simply making a pass of the vibratory roller over the mat in the static mode--without vibration.

A second alternative roller combination includes the use of two vibratory rollers, using one operated in the breakdown position and one operated in the second position. In this case, both rollers should be kept close to the paver and both machines should be operated in the vibratory mode. For most Superpave mixtures, even those that are polymer modified, a static steel wheel roller is not needed. If marks are present, they can usually be easily eliminated by making a final pass over the pavement surface with the second vibratory roller operated in the static mode. In many instances, a higher degree of density can be obtained with the two vibratory rollers being operated in echelon (essentially side by side), one on each side of the lane being place and compacted. In this situation, there is no problem with roller marks since the two vibratory rollers can easily remove their own marks due to the high mix temperature when the compactive effort is applied.

**Key Factors:**

The key to compacting a stiff Superpave mixture is to roll the material while it is as hot as possible. Keeping the rollers--in any combination--as close to the paver as possible is extremely important. Properly designed, a Superpave mix is supposed to have enough internal stability to support the weight of the compaction equipment without pushing or shoving. With the correct aggregate properties, such as crushed count and gradation, the stiff mix must be rolled while the viscosity of the binder material is still low--when the temperature is high--in order to be able to reorient the aggregate particles under the applied compactive effort and to densify the mix.

It has been found that, in general, the required degree of density can be obtained in the mat with fewer roller passes over any point in the pavement surface when a pneumatic tire roller is used in the
breakdown position, with a double drum vibratory roller in the second position, compared to the same
two rollers used in the reverse positions--vibratory roller first and pneumatic tire roller second. Fewer
roller passes means a more efficient and economical compaction operation.

CHARACTERISTICS OF TENDER HMA MIXTURES:

Not all asphalt concrete mixtures that meet the Superpave requirements exhibit high stiffness
during the compaction process. Some of these mixes are quite tender--they move or shove excessively
under the weight of the compaction equipment while being rolled. These tender mixtures need to be
treated very differently than stiff mixes in order to be properly compacted to the required level of density.

Until recently, emphasis has been placed on designing coarse graded Superpave mixes. These
mixes have gradations which lie on the bottom side of the so-called maximum density line when plotted
on 0.45 power gradation graph paper. In some cases, the gradation of the combined coarse and fine
aggregate lies completely beneath maximum density line. In other cases, a S-curve gradation is
employed. In the latter case, the gradation starts out on the fine or upper side of the maximum density
line in the coarse aggregate portion of the gradation but then dips or curves down below the maximum
density line as the gradation gets finer. The gradation of the aggregate then passes under--on the coarse
side--of the maximum density line.

The use of a polymer modified asphalt binder in the Superpave mix typically does not overcome
the primary causes of a tender mix, as discussed below. Mixtures that contain a non-modified binder that
exhibits tender characteristics generally also have tender properties when the standard binder material has
been replaced with a modified binder in the same mix.

Low VMA Content:

When the combined grading of the coarse and fine aggregate incorporated into the mix passes
beneath the maximum density line but immediately adjacent to it, the resulting HMA mix typically has a
minimal voids in mineral aggregate (VMA) content. Further, the change in VMA with a change in binder
content is often very small--there is a relatively flat curve when a graph of binder content versus VMA is
drawn over a range of 1.5 percent binder content in accordance with the Superpave mix design
procedures. Such mixtures are typically very sensitive to fluids content--the combination of asphalt
binder content and moisture content--due to the low VMA content of the HMA mix. For these mixes, a
small variation in the amount of binder material added to the mix and/or the presence of residual moisture
content in the mix (the aggregate does not get completely dry when passing through the batch plant dryer
or through the drum mix plant) results in a mix that is tender.

If the binder content in a mix with a low VMA content is too high--usually only 0.2 to 0.3 percent
above the optimum value--the film thickness of the binder material increases and the mix becomes "over-
lubricated". Similarly, if all of the moisture is not removed from inside of the aggregate particles before
the binder is added to the mix, some residual moisture may be retained in the internal pores of the
aggregate. This moisture prevents a portion of the asphalt binder material from being absorbed into the
aggregate (which was taken into account during the mix design process since the aggregate was
completely dried in the laboratory before the binder material was added). The result is again an increase
in the film thickness of the binder material around the coarse and fine aggregates due to the presence of
the non-absorbed asphalt cement on the outside the aggregate instead of being inside the aggregate.

Even with a high crushed face content in the combined coarse and fine aggregate materials, it is
very possible to design a HMA mix which is very sensitive to fluids content when the VMA content of
the mix approaches the minimum value permitted for the nominal maximum size aggregate incorporated
into the mix. Aggregate gradations which plot immediately adjacent to the lower side of the so-called
maximum density line usually produce mixtures with very low VMA content and thus tender mixes when an excess of fluids content--binder content and/or moisture content--is present in the material. Such mixtures lack the internal stability to support the weight of the compaction equipment during the rolling process.

**High VMA Content:**

The same problem with a high fluids content also exists when the combined coarse and fine aggregate material results in a HMA mix which has a very high voids in mineral aggregate content--more than 1.5 percent above the minimum value required for a given nominal maximum size aggregate used in the mix. If the combined coarse and fine aggregate material produces a gradation similar to the one shown in Figure 2, near the control points at the bottom side of the graph for a coarse graded mix, then the HMA mix will typically have a high VMA content.

According to Superpave mix criteria, the design air void content in the mix is usually 4.0 percent. As with any HMA mix, asphalt binder material is added to the mix to fill up the voids in the mineral aggregate until the 4.0 percent air void content is reached. If the mix contains a high VMA content, more binder material is added to achieve the desired air void content. This, in turn, results in a higher binder content in the mix and a higher binder film thickness around the aggregate particles. In this case, the mix becomes “over-lubricated” with too much asphalt binder material. The final result is a mix that is tender during the construction/compaction process due to a lack of internal stability in the mix and thus a mix that may later rut under applied traffic loads.

Mixes with high VMA contents typically do not contain enough mastic (fine aggregate and mineral filler) material in the mix to hold the mix together. The applied load is then carried by the binder material instead of by the aggregate. If the VMA is more than 1.5 percent above the minimum value, it is often recommended to add fine aggregate and/or mineral filler material to the aggregate in order to lower the voids in mineral aggregate content of the mix. Indeed, recent changes in the criteria for coarse graded Superpave mixtures have increased the allowable range for the dust-to-binder ratio from 0.6 to 1.2 to a range of 1.0 to 1.6 in order to increase the mastic portion of the HMA mix and significantly reduce the potential tenderness of the mix during construction and the potential for rutting or permanent deformation of the coarse graded mix under traffic.

**TENDER MIX TEMPERATURE ZONES:**

**Movement of the Mix:**

HMA mixtures that have an excess of fluids content due to too much binder, too much moisture, or a lack of mastic content are normally very difficult to compact. This is due to the tendency for the mix to move under the applied compactive effort of the rollers. This movement occurs in two directions.

In the longitudinal direction, the mix will shove in front of the steel wheels of both a vibratory roller and a static roller. A bow wave will form in front of the drums and the HMA material will “hump up” before the drum of the roller reaches that point on the surface of the mix. Indeed, depending on the degree of tenderness of the mix, mix located up to 150 mm (6 in) in front of the roller may start to move before the roller gets there. In extreme cases, the mix may start to move while it is still 300 mm (12 in) or more in front of the first drum of the steel wheel roller. This may occur whether the roller is operated in the vibratory mode or static mode.

Such longitudinal movement of the mix is normally accompanied by checking of the mix--the development of short, transverse cracks in the surface of the HMA material. Again, depending on the degree of the tenderness of the mix, the checks or cracks can be found as close as 25 mm (1 in) apart if
the mix is very tender to 75 mm (3 in) apart if the mix is only slightly tender. In terms of transverse length, the checks or cracks may be as short as 50 mm (2 in) if the mix is only slightly tender to a length of 200 mm (8 in) or more if the mix is very tender.

A tender mix will also move in the transverse direction. Depending on the position of the edge of the steel wheel roller drum on the unsupported edge of the pavement layer, it is possible for a tender mix to widen out transversely during the compaction process. In some cases, if the edge of the roller drum is located just inside the unsupported edge of the asphalt concrete mat, the mix may creep out laterally a distance of 100 to 200 mm (4 to 8 in) or more. Such transverse movement of the HMA material makes it very difficult to achieve the desired level of density in the mix at that location as well as very hard to make a good longitudinal joint if another lane is to be constructed next to the first lane.

If the mix is tender enough, the mix will hump up on the outside edge of the steel wheel roller drum. This is seen in Figure 2. The lateral or shear force at the edge of the drum is great enough to de-compact the HMA material and shove it sideways. Such movement (cutting of the mix) is usually found whenever the steel wheel roller, operated in either the vibratory or the static mode, makes any type of turning movement such as at the end of a roller pass. The de-compacted mix in the hump formed next to the edge of the drum is normally accompanied by checking or cracking of that mix, as shown in Figure 3.

Three Temperature Zones:

HMA mixtures that have tender characteristics still have to be compacted to a minimum level of density or a maximum level of air void content. Because of the lack of internal stability in the mix, however, the compaction of a tender mix is often very difficult. It has been found that a mix that has tender properties may be able to be compacted to the proper density by taking advantage of the three temperature zones which normally exist in that tender mix.

In the first, or upper, temperature zone, the asphalt concrete mix is relatively stable during the compaction process. Within the temperature range from laydown (160° C to 140° C or 320° F to 285° F, depending on the use of polymer modified binder and other factors) down to about 115° C (240° F), the HMA material is stable under the applied compactive effort. In this upper temperature range, the mix will
not shove or check under the rollers regardless of whether a vibratory roller or a static steel wheel roller is used to compact the mix.

The lower limit of this upper temperature zone is not an exact value--it depends on the characteristics of the mix, the rate of cooling of the mat, the thickness of the layer, environmental conditions, and the type of roller used--vibratory or static steel wheel. In some cases, this value may be as high as 120° C (250° F) or higher while in other cases it could be as low as 110° C (230° F) or lower.

The middle temperature zone--the problem range--extends from approximately 115° C (240° F) down to about 90° C (195° F). In this temperature range, the mix will move, shove, and check under the applied compactive effort. A bow wave will form in front of the steel drums of the roller and the mix will crawl longitudinally. The mix will also move laterally or transversely and the mat will widen out if the edge of the roller is not positioned properly over the unsupported edge of the asphalt concrete mat by at least 150 mm (6 in). In general, however, the mix will not move in this intermediate temperature zone when compacted using a pneumatic tire roller. In this middle temperature zone, the HMA material lacks the internal stability to support the weight of the steel wheel compaction equipment.

As with the upper temperature zone, the temperature range for the middle zone is not an exact value. This zone may start at a temperature of 120° C (250° F) or higher or at a temperature of 110° C (230° F) or lower. The tender zone may extend down to a temperature of 80° C (175° F) or lower or may stop at a temperature of 95° C (205° F) or higher. In general, for many mixes, the tender zone ranges from approximately 115° C (240° F) down to about 90° C (195° F), as discussed above.

The lower temperature zone extends from the end of the tender or intermediate temperature zone down to approximately 70° C (160° F) or even lower. Within this temperature range, the mix is cool enough to regain the internal stability necessary to support the weight of the compaction equipment. It is possible, but usually very difficult, to achieve the required degree of density within this relatively narrow temperature range if the mix has been de-compacted during the rolling of the mix when the mix temperature was in the middle temperature zone.

COMPACATION OF TENDER HMA MIXTURES:

In order to compact a HMA mixture which has tender characteristics and moves under the rollers in the middle temperature zone, a contractor has one of two choices. First, all of the compactive effort can be applied in the upper and/or the lower temperature zones when the mix is internally stable and does not move, shove, or check under the steel wheel rollers. In this case, no compactive effort is applied to the mix when the mix temperature is within the middle or intermediate temperature zone. Second, if it is necessary to roll the mix while the temperature is within the middle zone, a pneumatic tire roller can be employed as the intermediate roller since the mix will typically not shove in front of the rubber tires on this type of roller as it will in front of a steel wheel roller drum in this middle temperature zone.

Avoiding the Tender Temperature Zone:

In order to compact a HMA mix that is stiff, it is necessary to roll it as close behind the paver as possible, as described above. In order to compact a HMA mix that is tender, it is also necessary to roll it as close behind the paver as possible in order to take advantage of the upper temperature zone in the mix.

For most Superpave asphalt concrete mixtures that exhibit tender characteristics, the upper temperature zone ranges from the laydown temperature down to about 115° C (240° F). Within this range of temperatures, the tender mix must be compacted to as high a density as feasible, as quickly as possible. For most stiff HMA mixtures, one roller can be placed behind another roller, in a "roller train" fashion. For most tender HMA mixtures, however, in order to obtain the required minimum level of density
(maximum air void content), it is necessary to place two rollers on the mat within the upper temperature zone.

**Use of Two Double Drum Vibratory Breakdown Rollers:**

Perhaps the most efficient method to compact a tender mix within the upper temperature range is to use two double drum vibratory rollers in echelon (almost side-by-side). As illustrated in Figures 4 and 5, one double drum vibratory roller can operate on one side of the mat and the other double drum vibratory roller can operate on the other side of the mat. In essence, when one roller moves toward the paver on one side of the lane, the other roller also moves toward the paver at the same time on the other side of the same lane. The rollers operate together, moving forward and backward at the same time on different portions of the mat. The purpose of this compaction process is to get as much density in the mat as possible before the temperature of the mix drops into the middle or tender temperature range and the mix begins to shove and move under the steel wheel rollers.

![Figure 4: Two Double Drum Vibratory Rollers in Echelon Behind the Paver](image1)

![Figure 5: Two Double Drum Vibratory Rollers in Echelon Behind the Paver](image2)

The exact roller pattern used depends on many factors. Some of those factors include the width of each double drum vibratory roller used, the width of the lane being placed, the temperature of the mix immediately behind the paver screed, the temperature at which the mix starts to move and shove (the start of the tender zone), and the maximum frequency at which each vibratory roller can operate. Ideally, the two double drum vibratory rollers should be of the same make, model, and condition. This will assure that the compactive effort applied to the mat is equal across the width of the lane.

In order to adequately compact an asphalt concrete mixture, it is proper to extend the edge of the vibratory or static steel wheel roller drum over the unsupported edge of pavement and/or over the longitudinal joint by at least 150 mm (6 in). Theoretically, therefore, one would need a 3.96 m (13 feet) wide roller to compact a 3.66 m (12 feet) wide pavement, allowing for a 150 mm (6 in) overlap of the outside edges, whether unsupported or a longitudinal joint. Since no roller exists that is 3.96 m (13 feet) wide, in order to uniformly compact the mix using rollers of normal width, it is necessary to overlap the edge of the previous roller pass by a minimum of 150 mm (6 in). Vibratory rollers used for most highway paving projects typically are manufactured in three drum widths—1.67 m, 1.98 m, and 2.13 m (66 in, 78 in, or 84 in, respectively).

If the width of the lane is 3.66 m (12 feet) and the roller being used has a width of 2.13 m (84 in or 7 feet), then the whole width of the lane can be covered with two passes of the double drum vibratory
roller--one of the left side and one on the right side, allowing for a 150 mm (6 in) overlap of both edges of the lane as well as a 150 mm (6 in) overlap of the drum in the center of the lane. If a narrower double drum vibratory roller is employed, however, with a drum width of only 1.98 m or 1.67 m (78 in or 66 in, respectively), then three passes of the roller are required in order to compact the whole width of a 3.66 m (12 feet) wide lane and have the correct amount of overlap over the unsupported edge and/or longitudinal joint and between internal passes within the lane width.

Roller Patterns:

A roller pattern that has been used to compact a 3.66 m (12 feet) wide lane with two double drum vibratory rollers that are either 1.98 m or 1.67 m (78 in or 66 in, respectively) wide, operating in echelon in the breakdown position directly behind the paver is as follows: Both rollers are operated at maximum frequency and at an amplitude setting that is proper for the layer thickness being placed. The first roller compacts the left side of the roadway with two passes (numbers 1 and 2) up and back in exactly the same position, hanging over the left edge of the lane by 150 mm (6 in). (A pass is defined as one time over a point in the pavement surface). That roller then makes a pair of passes (numbers 3 and 4)--up and back--over the center of the lane. The last three passes (numbers 5, 6, and 7) are made directly on top of the first two passes on the left side of the mat. At the end of pass 7, the roller continues up to the back of the paver and then begins the pattern over again.

The second double drum vibratory roller makes its first four passes (numbers 1, 2, 3, and 4)--up, back, up, and back--over the right side of the mat, hanging over the right edge of the lane by 150 mm (6 in). The next two passes, numbers 5 and 6, are made up the center of the lane over the top of the two passes completed by the other roller. For pass number 7, the second roller again moves back to the right side of the lane and makes its last pass over the top of the first four. At the end of pass 7, the roller continues up to the back of the paver and then begins the pattern over again.

Using this roller pattern, and allowing for overlap of the unsupported edge of the lane and/or the longitudinal joint, as well as the overlap between the roller drums, the width of the lane is compacted as uniformly and efficiently as possible. Most importantly, the compaction process can be completed before temperature of the mix reaches the middle or tender temperature zone. In this way, attempted compaction of the mix in the tender zone can be avoided by essentially putting the intermediate roller in the breakdown or initial position together with the first roller.

In most cases, the required level of density can be obtained using only the two double drum vibratory rollers operated in echelon in the breakdown position. Generally, no additional rollers are needed--even a static steel wheel finish roller. Roller marks can be taken out with the initial rolling. No shoving or movement of the tender mix occurs since no rolling is done in the intermediate or tender temperature zone. This roller pattern typically is the most efficient and economical means to compact a tender asphalt concrete mixture.

Rolling in the Tender Temperature Zone:

If only one double drum vibratory roller is available and if a pneumatic tire roller is available, then the rubber tire roller can be used in the intermediate position--in the tender zone. The vibratory roller should make as many passes as possible over the width of the lane before the temperature of the mix drops to the point that the mix starts to move and check with an additional roller pass. Once the mix starts to shove and de-compact under the drum, all compaction with any steel wheel roller--operated in either the vibratory or static mode--should cease.

An asphalt concrete mixture, even a tender one, does not normally shove in front of the tires of a pneumatic tire roller. The rubber tires on this type of roller tend to tuck the mix back under the tires
instead of shoving it forward. Thus, in the middle or tender temperature zone, a pneumatic tire roller can be used to accomplish what a steel wheel roller can not do--compact the mix. It is important to note, however, that it may be difficult to use a pneumatic tire roller in the middle temperature zone on some polymer modified mixtures, particularly if the mix has been modified using a latex (styrene-butadiene-rubber) type material. Pickup of the mix on the tires might be impossible to avoid in some instances.

If a pneumatic tire roller is used in the intermediate position on a tender mix, it will be necessary to use a static steel wheel roller to complete the compaction process. The finish roller is employed to remove the marks of the rubber tire roller and to increase the density of the mix to the final, required level. Care must be taken, however, that the finish roller does not operate in the middle temperature zone and actually de-compact the mix instead of compacting it. The static steel wheel finish roller should be moved closer and closer toward the back of the rubber tire roller until the mix starts to move or shove under the drums. This is an indication that this roller is inside the middle or tender temperature zone. If this occurs, the finish roller should be kept farther back from the intermediate roller and operated completely within the lower temperature zone.

Using this roller pattern to compact a tender mix is not as efficient as using the two double drum vibratory rollers in echelon in the breakdown position since three rollers are needed--a double drum vibratory breakdown roller, a pneumatic tire intermediate roller, and a static steel wheel finish roller. This pattern, however, can be used, if necessary, to obtain the required level of density in a tender mix.

SUMMARY:

It is possible to properly compact a Superpave HMA mixture that is relatively stiff or a Superpave HMA mixture that is tender. In either case, it is suggested that the breakdown or initial roller or rollers be kept as close to the back of the paver as possible in order to compact the mix while it is hot. If the mix is stiff, the roller pattern used should ideally consist of a pneumatic tire roller, followed by a double drum vibratory roller, followed, if necessary, by a static steel wheel finish roller. If the mix is tender, the roller pattern used should consist of two double drum vibratory rollers operating in echelon directly behind the paver, followed, if necessary, by a static steel wheel finish roller, with no roller operating in the intermediate or tender temperature zone.

For tender mixes, the real solution to the tender mix problem is two-fold. If the problem is with the gradation and/or the properties of the aggregate incorporated in the HMA mix, the aggregate should be changed. If the problem is with an excess of fluids content--either asphalt binder material and/or moisture, the binder content of the mix should be adjusted and/or the aggregate should be properly dried in the plant before the binder is added during the production of the mix.

For tender mixes, overcoming the deficiencies in the mix in the compaction process can be done--the required level of density can be obtained with an adjustment in the roller pattern used. The mix, however, might still deform or rut under traffic. A mix that can not support the weight of the rollers during the compaction process may not be able to support the weight of the applied traffic with time. Thus the proper solution to a tender mix compaction problem is to change the properties of the mix being compacted.