Introduction

It is desirable to conduct all hot mix asphalt (HMA) paving operations without segregation of the mixture. Due to many factors, it is very difficult to eliminate segregation completely. The next best alternative is to build HMA pavements with the least segregation possible. In order to do that, it is necessary to understand the nature of segregation in HMA, as well as its causes and the preventive measures to be taken. Methods of recognizing and avoiding segregation in production and construction of HMA are presented in this chapter. In addition, the analysis of segregated mixes is discussed, and corrective measures are given.

Overview of Segregation

Segregation in HMA is a non-uniform distribution of the various aggregate sizes throughout the mass. The finished mat has a varied texture and more than likely does not meet specification requirements for surface texture, smoothness, or density (Figure 8.01). Segregated areas differ from the approved mix design, and the areas will not meet the volumetric properties required and discussed in *Determining Segregation Level* at the end of this chapter.

Segregation is not a phenomenon new to the HMA industry. It started to occur more commonly in the late 1970's when HMA mixtures experienced an

Figure 8.01 Segregated Hot Mix Asphalt Pavement

increase in the percent of material passing the 0.075 mm (No. 200) sieve and a corresponding decrease in asphalt content. The use of surge and storage bins increased, changes in plants occurred, and trucking increased. Segregation is receiving additional attention at this time for good reason: Agencies are demanding additional life from their pavements. Severely segregated pavements require maintenance sooner than properly constructed ones because of excessive moisture damage, raveling, and premature cracking.

➤➤ Types of Segregation

The most common types of segregation are:

- Random spots which occur intermittently throughout the roadway
- Chevron shaped spots at the beginning and end of truckloads
- Continuous longitudinal streaks at either or both sides of the lane
- Center of paver streaks

Each type of segregation is the result of a specific action in mixing and placing, and the segregation is prone to occur most often at five stages, as shown below. Careful observation and control of mixing and placing operations during theses stages can reduce or eliminate segregation in most asphalt mixes. The economic benefit of reducing or eliminating segregation has been recognized universally, and agencies that specify asphalt pavements are increasingly requiring more to control segregation.

➤➤ Segregation Trouble Spots

Segregation may be caused by the methods used in aggregate handling, and in mixing, storing, transporting and handling the mix, where a condition is created that favors non-random distribution of the aggregate sizes. Years of research and observation have shown that segregation most often occurs at the following stages:

- Mix design (as a factor in segregation potential)
- Aggregate handling and stockpiling
- HMA plant production, such as at the:
  - A. Cold bins; loading and feeding
  - B. Hot bins
  - C. Drum mixer operations
  - D. Hot elevator
  - E. Pugmill bin gates
  - F. Surge and storage bins
  - G. Discharge systems
- Trucking operations
- Paver operation

There may be other stages, but these five are the most common and can readily be detected and corrected. Worn or improperly maintained mixing and paving equipment also leads to problems in handling and placing the mix. A technician can visually identify segregation and quantify it from an extraction analysis. The required asphalt content of a mix is directly proportional to the surface area of the aggregate – the finer the mix, the larger the surface area, and the greater amount of asphalt required to coat the aggregate. This relationship can determine whether the mix segregated before or after mixing. The ability to pinpoint the source of the segregation will minimize hours of review work to solve the problem. Detailed evaluations done in the laboratory are described in the section, *Pinpointing Segregation*.

➤➤Segregation Potential in Mix Design

Certain characteristics in the makeup of a mix design can increase the potential for segregation in the produced HMA. These characteristics of the mix are the result of mix designers reacting to the realities of modern highway transportation. Increased truck traffic, heavier loads and increased tire pressures have brought about mix designs with a tougher aggregate skeleton. These tougher HMA mixtures may be segregation prone. In addition, environmental restrictions on the amount of fines (dust) that may be released into the atmosphere have resulted in mixes with a higher percentage of material passing the 0.075 mm (No. 200) sieve. This decreases the voids in the mineral aggregate (VMA), therefore reducing the asphalt demand. This reduction in asphalt reduces the cohesion of the mixture, as well as its workability and durability.

The potential for segregation in HMA is increased by:

- Lower asphalt contents
- Higher percentages passing the 0.075 mm (No. 200) sieve
- The use of larger maximum size aggregates
- Coarser and gap-graded gradations within established specification sizes

A lower asphalt content makes the mix prone to segregation, regardless of its gradation. Lower asphalt contents are often the result of trying to achieve volumetric properties, such as air voids, by varying the asphalt content. A low VMA in the aggregate structure and a high percentage of material passing the 0.075mm (No. 200) sieve will result in a low asphalt content, and consequently low cohesion of the mixture.

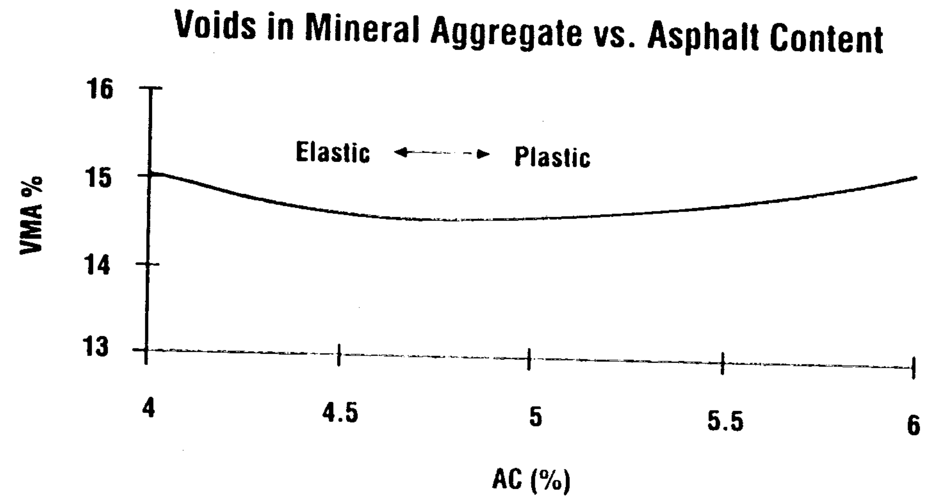

Figure 8.02 Typical VMA Curve

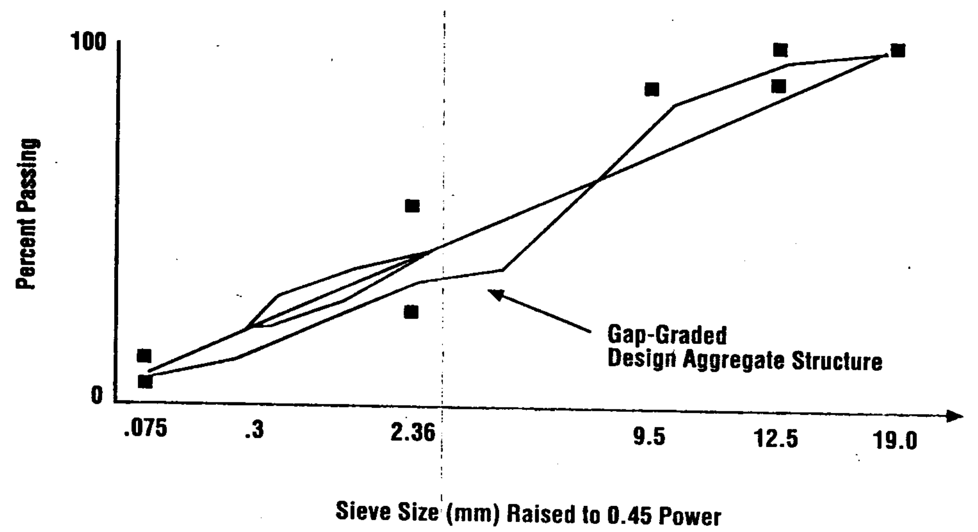

Figure 8.03 Gap-Graded Aggregate Gradation for HMA

A good method to analyze a mix for cohesion is to observe where the asphalt content falls on the VMA curve. For maximum cohesion, while maintaining an elastic mixture, the asphalt content should be slightly to the left of the minimum VMA value.

Figure 8.02 illustrates a typical VMA curve. The minimum VMA value occurs at 4.7 percent asphalt content (AC). The design AC should not be more than one-half of one percent (0.5%) less than the asphalt content corresponding to the minimum VMA value. This is only a rule of thumb, and it should be applied with common sense after evaluating each mixture. Experience has shown that mixtures with asphalt contents below this value are low in cohesion and are prone to segregate. Conversely, asphalt mixtures with a design AC above the value corresponding to the minimum VMA will be over-asphalted and can result in a plastic mixture prone to rutting and shoving.

An optimum asphalt content using these guidelines and Figure 8.02 would be between 4.2 and 4.7 percent. However, the lower limit does not provide enough asphalt to give the mix adequate cohesion and durability. If the design air voids (such as 4.0%) indicates an asphalt content at or near 4.2 percent, the mixture should be redesigned using material with less fines.

The curve in Figure 8.02 shows a typical relationship between VMA and asphalt content of a mixture with a high percentage of material passing the 0.075 mm (No. 200) sieve. The low point of the curve is the critical point of the mixture. This point indicates the value of AC that changes the state of the mixture from elastic to plastic. For maximum cohesion of the mixture – without making the mixture plastic – the asphalt content should be near the maximum of the 4.2 to 4.7 percent range.

Base mixtures with a maximum aggregate size of 50 to 75 mm (2 to 3 inches) are seeing greater use. In addition, some agencies have increased the maximum size of surface and intermediate courses in order to increase resistance to rutting. As the difference between the maximum and minimum size in a mix increases, the tendency to segregate increases. Large stone mixes by their nature are segregation prone.

Another potential cause of segregation in HMA due to its mix design is the gradation. When an aggregate gradation is near the coarse limit of its specification, or when it is gap-graded, the

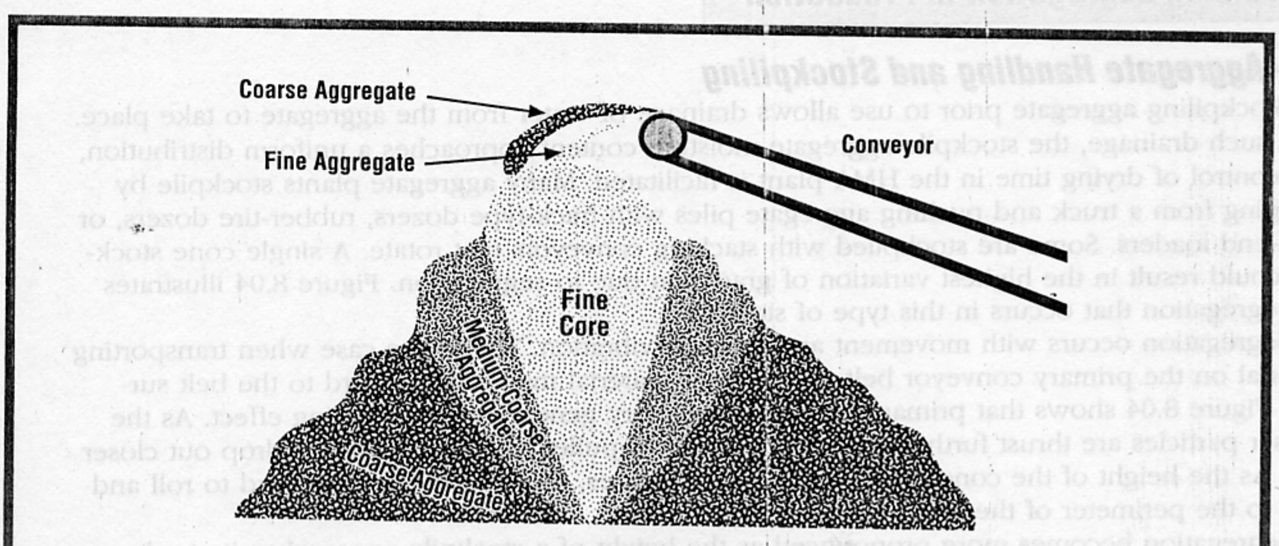

Figure 8.04 Cone Stockpile Segregation

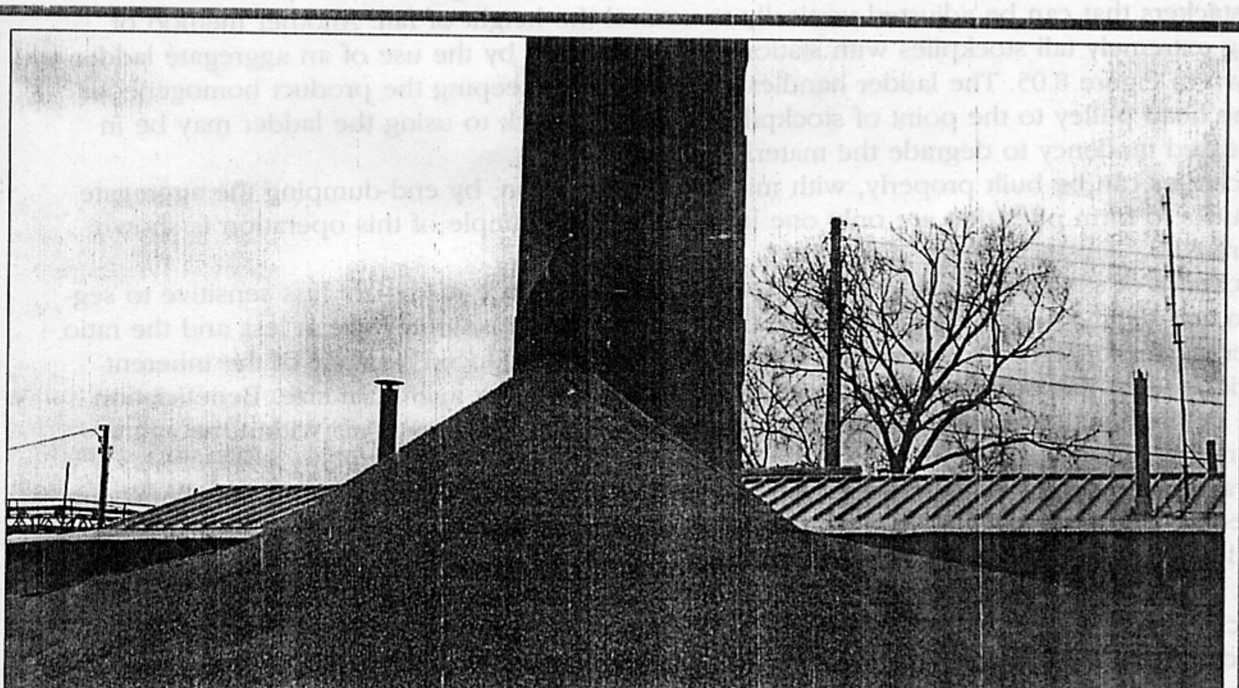

Figure 8.05 Cone Stockpile Built With Aggregate Ladder

potential for segregation is increased. Coarser aggregate gradations are often sought and these sometimes result in gap-graded mixtures. Figure 8.03 shows a gap-graded aggregate gradation.

The use of aggregate blends with diverse specific gravities of the coarser and finer materials also introduces the potential for segregation of HMA. Mixtures with this property tend to segregate during mixing and handling due to the differences in weight of the particles. This is particularly true if the coarse aggregate has a higher specific gravity.

➤➤Aggregate Handling and Stockpiling

Stockpiling aggregate prior to use allows drainage of water from the aggregate to take place. With such drainage, the stockpile aggregate moisture content approaches a uniform distribution, and control of drying time in the HMA plant is facilitated. Many aggregate plants stockpile by dumping from a truck and pushing aggregate piles with track-type dozers, rubber-tire dozers, or front-end loaders. Some are stockpiled with stacking conveyors that rotate. A single cone stockpile could result in the highest variation of gradation due to segregation. Figure 8.04 illustrates the segregation that occurs in this type of stockpile.

Segregation occurs with movement and through vibration. This is the case when transporting material on the primary conveyor belt, as the finer material moves downward to the belt surface. Figure 8.04 shows that primary conveyor trajectory generates a segregating effect. As the coarser particles are thrust further away from the head pulley, the finer particles drop out closer to it. As the height of the cone of the surge pile increases, the coarser particles tend to roll and slide to the perimeter of the pile.

Segregation becomes more pronounced as the height of a stockpile approaches its peak. Separation of aggregate particles can occur when the aggregate falls a great distance from the conveyor to the stockpile, and degradation can take place as the falling aggregate strikes the stockpile. Both can be minimized by keeping the stockpile at a high level or by the use of boom stackers that can be adjusted vertically to control the height of fall. Another method of building extremely tall stockpiles with stationary conveyors is by the use of an aggregate ladder as shown in Figure 8.05. The ladder handles segregation by keeping the product homogeneous from the head pulley to the point of stockpiling. The drawback to using the ladder may be in an increased tendency to degrade the material.

Stockpiles can be built properly, with minimum segregation, by end-dumping the aggregate from trucks to form piles that are only one layer deep. An example of this operation is shown in Figure 8.06.

Stockpiles of single-size fractions for intermediate and surface mixes are less sensitive to segregation and degradation. Segregation is reduced because the maximum size is less and the ratio of larger to smaller sizes is decreased. Degradation has been reduced because of the inherent beneficiation that has occurred during the processing to a smaller aggregate size. Beneficiation may be defined as the removal or partial destruction of deleterious materials within the aggregate particle.

A fractionating plant is designed to provide separate aggregate piles with a given pile having nearly equal aggregate sizes. A fractionating plant is one of the better processing alternatives for controlling segregation. Blending the various size aggregates together at the loadout point in the hot mix asphalt plant minimizes the effect of segregation and helps to achieve the desired product specifications. Today, most contractors use four or more cold feed bins to provide greater quality control at their HMA plants. Single size aggregates provide greater quality control but require more cold feed bins. It is not uncommon to see up to six or seven cold bins used by some contractors, and those who do, normally use single size aggregates to minimize stockpile effects.

In summary, tall conical stockpiles of aggregates should be avoided because coarser particles tend to roll down the sides of the pile. Stockpiles constructed by layers or material inclines with less than 30 percent slopes are preferred. Ledging the stockpile is also an excellent way to minimize segregation at this stage. Constructing stockpiles on a hard foundation provides drainage, helps to reduce segregation, as well as contamination of the mineral aggregate, and is considered good practice

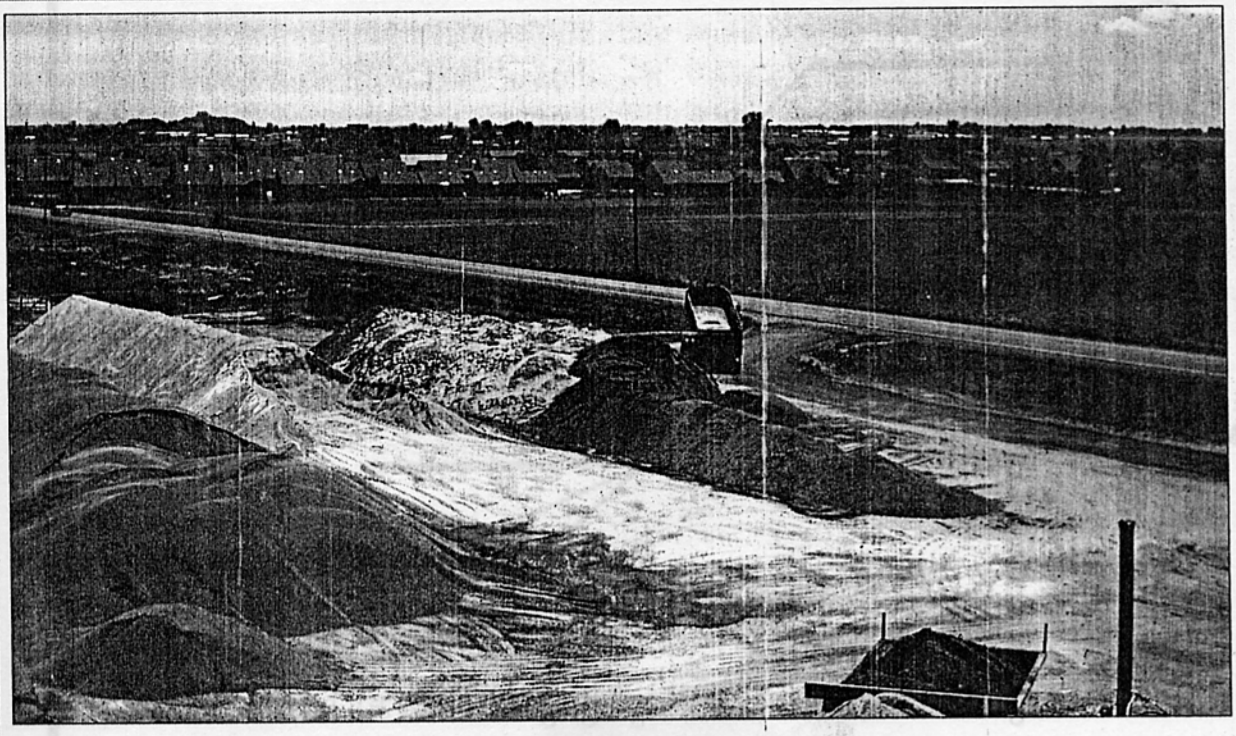

Figure 8.06 Building a Stockpile Properly

➤➤HMA Plant Production

Cold Bins Changes in aggregate supply and equipment require the loader operator to be more conscious of equipment operation. The manner in which the equipment enters the stockpile and operates can cause segregation in a stockpile or in a load of material. The loader operator should be alert for both segregation and variable moisture conditions.

Material placed in cold bins by a loader generally tends to form a conical shape, and coarse aggregates can separate at this point by rolling down the conical sides. On the other hand, the nature of the material draw onto the cold feed belt allows *reverse coning* to occur. Reverse coning is where coarse material falls to the middle of the cold bin, and it can lead to segregation on the belt and through the asphalt plant. One solution is to fractionate the aggregate; another is to keep the bins as full and level as possible. Yet another solution is to utilize self-relieving bottoms, which allow for a more uniform feeding of the cold aggregate all along the opening of the cold feed bin, eliminating bridging as a source of segregation. Cold bins are often equipped with a vibratory device to help provide a self-leveling effect.

Hot Bins Batch plant hot bins are prone to segregate by the screening process of the mineral aggregate. Screening action forces coarser aggregate to the far side of the bin and creates a pronounced pattern, from fine to coarse, at the inlet screen as shown in Figure 8.07. This pattern results from two factors: The way in which the aggregate flows across the screen; and the tendency for the finer material to slide down the near side of the bin. This process, if left uncorrected, will allow spotty segregation to occur. To correct this, baffle plates can be installed on the bin walls to remix material as it enters the bins. Even with the screening that they perform, batch plant hot bins do not fully correct segregation from poor stockpiling or cold feed operations.

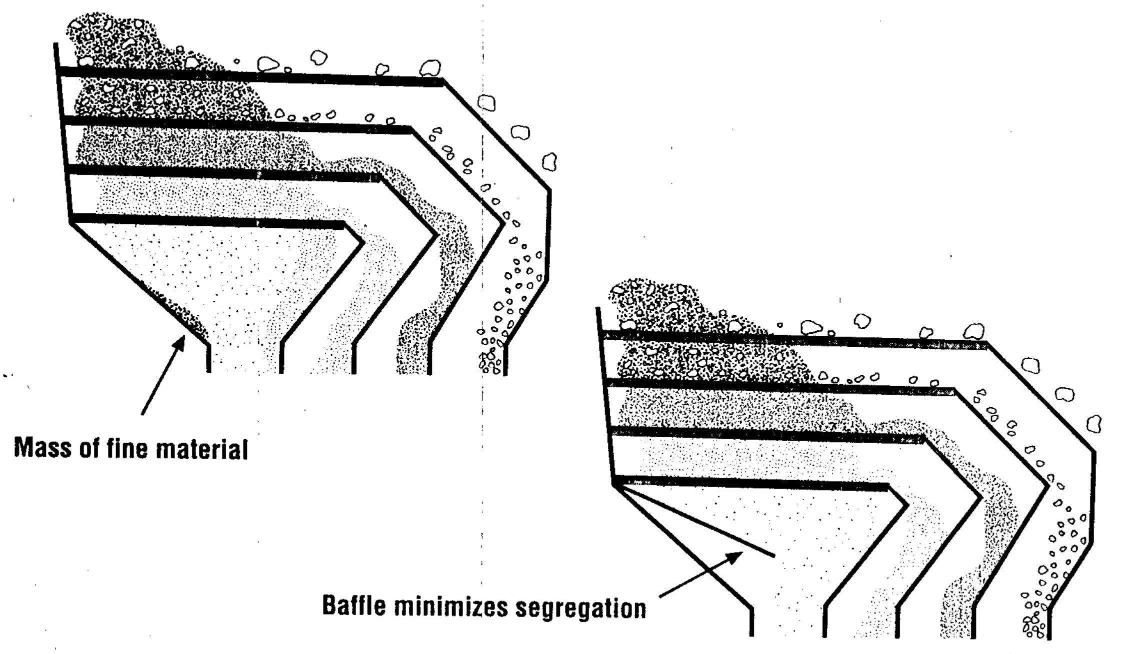

Figure 8.07 Hot Bins: Minimizing Segregation in Bin No. 1

Drum Mixer Operations In drum mix plants there are no hot bins. Stockpiles can be considered their equivalent, and there is no chance of segregated material remixing before the introduction of asphalt binder.

Segregation occurs in the drum, especially when starting and stopping production, due to the coarse material flowing through the drum at a slightly faster rate than the fine material. However, this can be alleviated by adjusting the starting and stopping times of the materials in the cold bins. Kickback flights or a dam can be installed in a drum to retard the flow and thereby increase the mixing time. In addition, the mixing time can be increased by extending the asphalt line farther into the drum or by decreasing the drum slope. An increase in the mixing time increases the asphalt coating of the aggregate and thereby the cohesion of the mix. This reduces the potential for segregation.

When the mix is discharged from the drum, the coarse and the fine particles tend to flow to opposite sides of the discharge chute. If this segregated material drops directly on a conveyor traveling on the line of the drum, the mix will remain segregated (Figure 8.08) all the way to the surge bin. Installation of a fixed plow in the drum (Figure 8.09), or otherwise restricting the discharge of the mix to a smaller area will decrease this segregation. Also, setting the drag conveyor at 90 degrees to the drum discharge (Figure 8.10) will eliminate or reduce segregation.

Hot Elevator Typically, asphalt mixes are discharged from the mixing unit and placed in surge or storage bins in two ways: drag slat and conveyor belt. To place material in the storage bin without segregation, the speed of these systems must be balanced with output tonnage. A small amount of material on a fast belt will segregate when it tumbles as it travels up the hot elevator, and when it is placed, or cast, into the bin. Coarser material will be cast to the far side of the drop chute or any other device installed to funnel material into the bin.

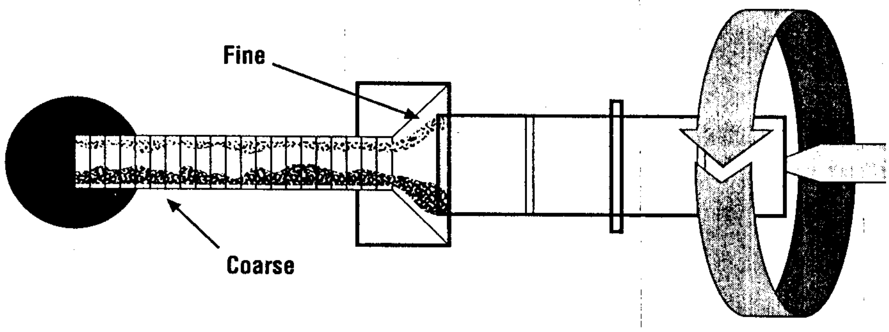

Figure 8.08 Segregation During Drum Discharge

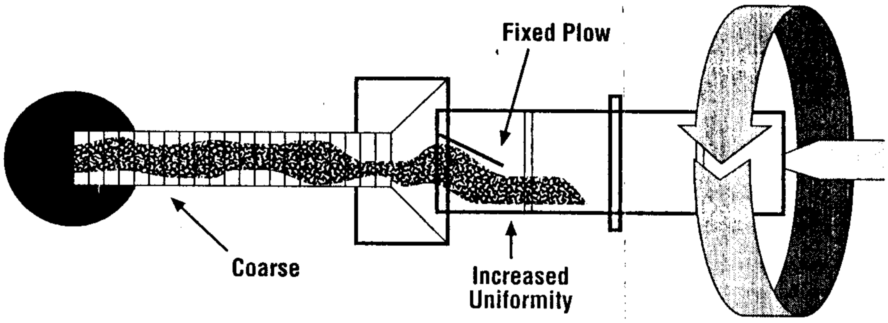

Figure 8.09 Uniformity During Drum Discharge by Fixing a Plow at Point of Discharge

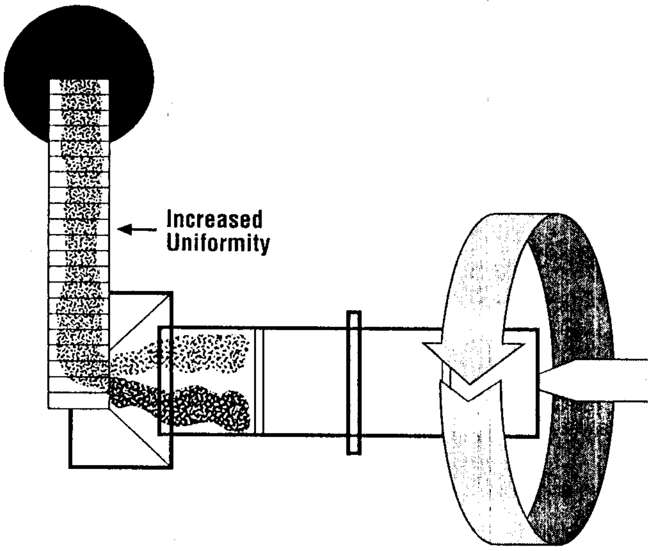

Figure 8.10 Uniformity During Drum Discharge by Turning Drag Chain 90°

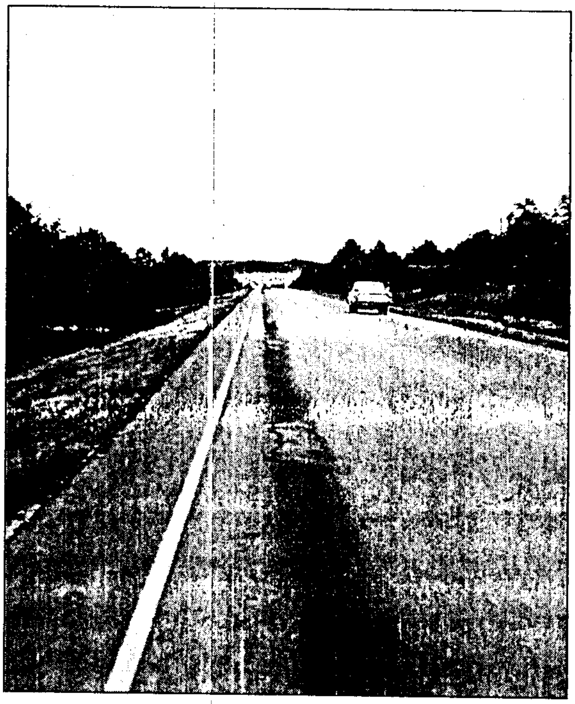

Figure 8.11 Fine Aggregate Segregation of HMA on the Roadway

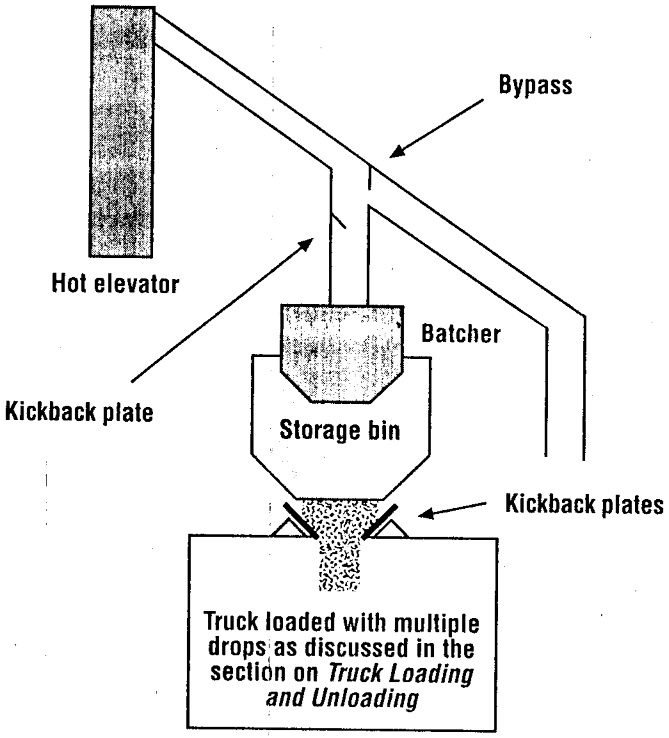

Figure 8.12 Plant Modifications to Avoid Segregation

Some storage systems allow material to be conveyed against a vertical side wall at the conveyor release point. This causes coarse aggregate to bounce back from the fine aggregate and produces a coarse-to-fine side throughout the bin. When dumped, the mix becomes coarse on one side of the truck and fine on the other, and results in continuous segregation along the side of a paving lane as shown in Figure 8.11.

Storage bins are normally fed through the use of a batcher, discussed later, and can be bypassed for direct loading if required. In these instances, segregation of the mixture bypassing the storage bin is very minimal. Segregation does occur when the bypass is locked off and the mixture now changes direction to enter the batcher. The installation of kickback plates, as shown in Figure 8.12, forces the remixing of coarse and fine aggregate within the mixture prior to entering the batcher. This technique is normally used on dated equipment, as most new units take this movement into account in their designs.

Pugmill and Bin Gates Discharge gate openings on pugmills are different from those on surge and storage bins. Batch plant pugmills empty all the mix in a single drop. Their gates open very wide and allow a straight drop into the truck. Trucks used in batch plant operations have traditionally been smaller and have therefore limited the coning effect in loading. Bin discharge gates that slide open slowly allow some dribble effect at the opening and closing mode. This is common to both the batch and drum mix plants that use surge or storage bins.

Several gate models are in use on surge and storage bins. They vary from rectangular to round, and can include plates and baffles. Gates are a common spot at which segregation occurs. Many agency specifications require clam or other type of gate openings that will not cause segregation. They open both transversely or longitudinally to the truck bed. Type of gate opening may be secondary to bin configuration in segregation control.

Surge and Storage Bins Segregation often occurs when material is placed into surge bins and storage bins, or "silos." A conveyor system places the mix into a "batcher," or similar discharge system. A batcher is a container with gates at the bottom, which sits above the silo and catches and releases material in order to regulate the flow of mix into the silo and reduce segregation. Timing systems on these units should be set in accordance with output tonnage to keep the mix from falling straight through the batcher into the silo and causing segregation by coning. For proper operation, the mix should be discharged into the silo in small batches. The batcher gate should be operated in a pulsating manner, and the batcher should never be completely empty during operation. For variable production rates, the gate timer should be adjusted accordingly.

Another method of reducing segregation in the silos is by the use of a rotating discharge chute at the top of the silo. In the rotating chute and plate systems, operation speed depends on tonnage output. Operating the device slowly will prevent material from being cast to the sides of the silo and causing a reverse cone effect, with coarse material on the outside and fine on the inside. The rotating chute has given way to the batcher in modern HMA plants.

Four silo variables govern the sensitivity of segregation:

- Diameter
- Height
- Cone shape
- Gate opening type

Each type of silo must be operated appropriately to obtain equal results. Diameter and height of the cone should be adequate to prevent reverse cone effects as mix leaves the unit. Segregation from these units can be corrected by adding another cone or batcher to the bottom. This remixes the material before it is released into trucks.

There are different types of silos with various side angles, gate openings, and inter-loading units. Some are more efficient than others. The ideal operating range for most silos is between 25 percent and 75 percent full. Segregation will increase below the 25 percent capacity as the mix falls below cone level.

Discharge Systems When segregation occurs in the silo, a cone unit placed on the bottom of the silo will produce reverse coning and remix the material. In addition, baffle plates can be installed on the bottom of the silo to kick coarse aggregate back into the mix. This can be seen in Figure 8.12, Plant Modifications to Avoid Segregation.

Retrofits to asphalt plants are a rather common occurrence. Preventing segregation is a good reason to look at retrofitting an asphalt plant. With some minor reconfiguration, benefits well beyond the cost of the retrofit can be obtained through increased pavement life.

Avoiding Segregation in Construction

➤➤ Trucking Loading and Unloading

HMA can segregate as it is loaded into trucks from either pugmill or surge systems. Trucks are much larger today, and care should be taken during loading to prevent coning in the truck bed. Both pug and surge systems are covered by the same loading recommendations. There should be at least three drops of material—front, back, and center, as shown in Figure 8.13. Even though it is more time consuming, proper care in truck loading can be extremely important to the quality of pavement produced.

The "length of slope" of a pile of HMA is of particular importance when considering truck loading. A single discharge into the truck tends to provide the longest slopes over which the stones can separate. The mix should discharge first near the bulkhead to produce a stacking effect for the front and sides. The second drop produces the same conditions at the rear of the truck. The third drop, in the middle, should overlap the conical sides of the first two. This procedure does not eliminate segregation, but spreads it out and minimizes the effect.

The method used to unload the haul truck into the paver hopper may also contribute to a segregation problem, again by generating longer slopes over which the particles may separate within the dumping load. Most problems of this kind develop from slowly raising the truck bed while dumping. When the truck is in place to dump onto the roadway, the bed should be partially elevated before the tailgate is released. This permits the mix to move in mass and to flood the hopper, thus preventing the coarse aggregate from falling out first and causing spotty segregation patterns.

➤➤ Paver Operation

In addition to the operations through the plant and the truck loading, the possibility of segregation in the paving operation exists. Segregation that is intermittent can usually be related to the trucks or the loading procedure. Continuous segregation can generally be attributed to operations and material handling occurring in the paver. An intermittent type of segregation that is an exception and shows up on the road as an open textured "chevron," pointing in a direction opposite to that being paved, is illustrated in Figure 8.14. In most cases the spacing of these open textured areas is end-of-load associated. Dumping the wings, thus sending coarser material to the middle of the hopper, after running the paver dry and then moving forward before the hopper is re-charged can create this form of segregation.

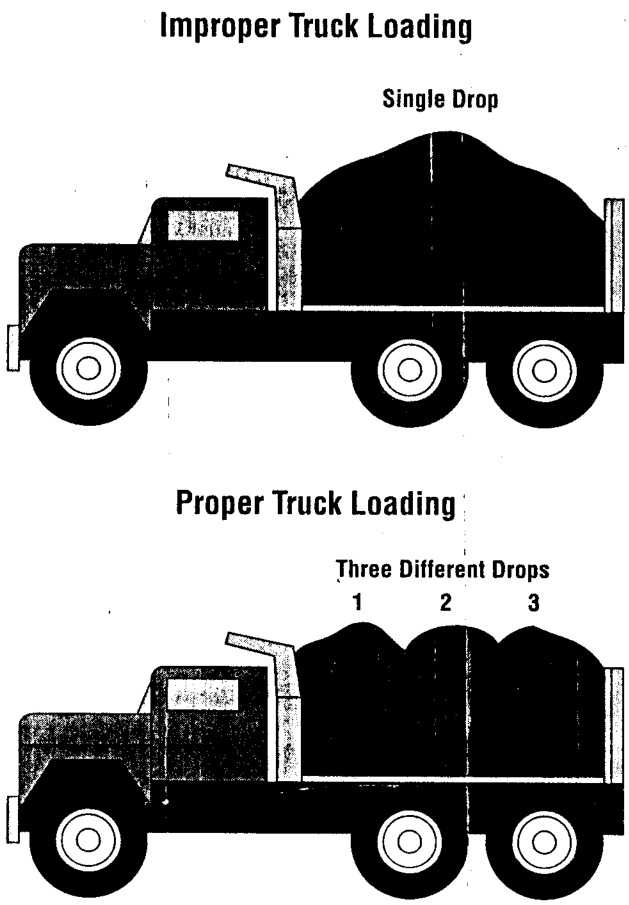

Figure 8.13 Improper and Proper Methods of Loading Trucks With HMA (AASHTO)

If the hopper wings are dumped, care should be taken when dumping them, and it should only be done with other, non-segregated material in the feeder area. While this may not completely solve the problem, it will give the coarse material an opportunity to mingle with more homogeneous material, thus minimizing the segregation effect. Dumping the wings and running the hopper dry before recharging causes chevron or wing type segregation. Once the paver is in motion, the hopper should maintain 25 percent or more of its capacity at all times. The paver should not be operated when the material is below the hopper deck.

➤➤Paver Segregation Areas

Both continuous and repeated forms of segregation can be linked to the paver and, in particular, to its material handling system. There are specific areas across the mat where visible segregation may occur. These are at the:

- Center screw conveyor (auger) support
- Outside edges of the flight feeders (drag conveyors)
- Underside of the outboard screw conveyor (auger) supports
- Outer edges of the screed

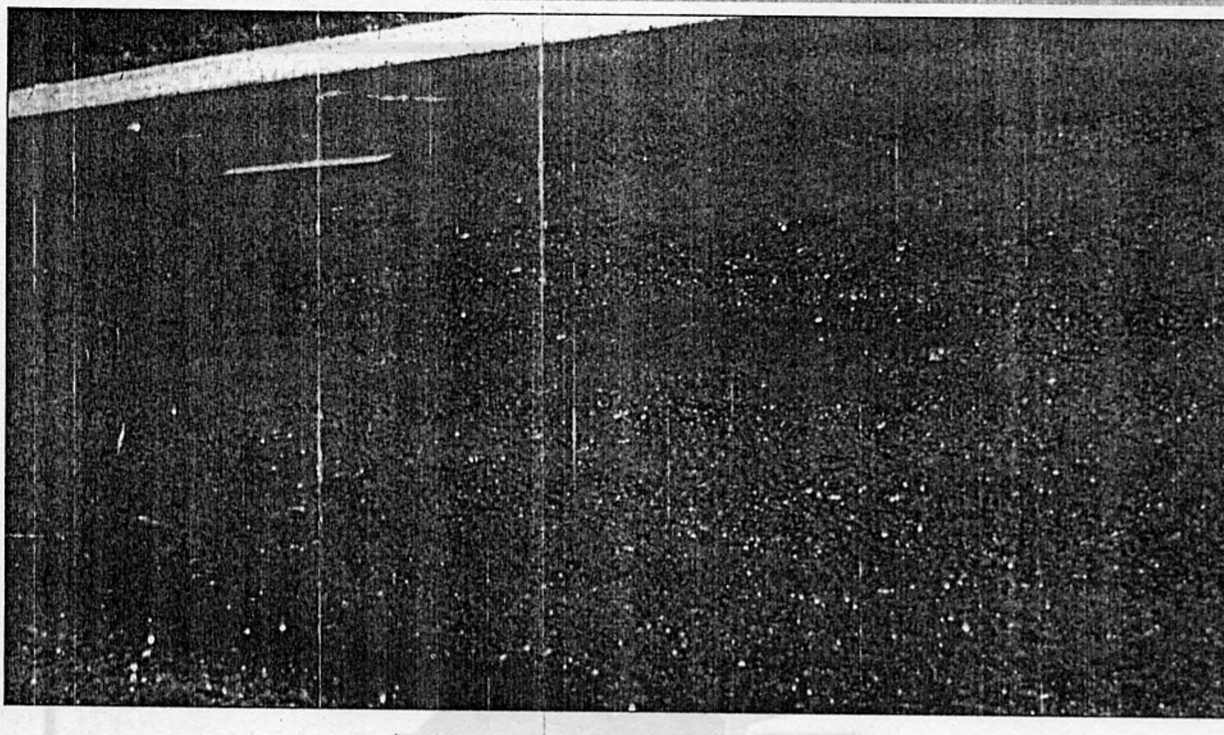

Figure 8.14 Chevron-Shaped Segregation on the Roadway

Center Screw Conveyor Support, or Center Gear Box A longitudinal, segregated strip often develops in the center of the paved lane under the center screw conveyor support. This segregation is not always visible at the time of paving. More recent developments in screw conveyor (auger) systems that can be raised and lowered have shown reasonable success in helping solve the problem. This new approach utilizes a separate drive motor and case for the screw conveyor drive and eliminates the previous triangular-shaped drive case. In this way, feeder discharge can directly surge fill the cavity under the screw conveyor drive case. Success has also been achieved in eliminating the segregated area by simply raising the screw conveyors to allow unrestricted material flow into the center area. Once the cavity is filled, the roll distances are shortened and segregation is minimized, but operator care must be taken to ensure that a proper screw conveyor chamber level is maintained between truckloads to keep the cavity filled.

Outside Edges of the Flight Feeders A few mixes have shown a tendency to segregate at the outside edges of the flight feeders for the same "fall distance" reasons as the center support. The mix could also segregate from flowing around the corner and then back under the paver's main frame. Most new pavers are equipped with a baffle to minimize the flight feeder conveyors' ability to carry material forward on their return path. This baffle has also been successful in reducing the roll distance at that point.

The most important action to reduce segregation in these areas is to keep the screw conveyor chamber filled to a level at or about the top of the conveyor shaft. This fills the cavity ahead of the flight feeders and minimizes the opportunity for the material to flow forward after turning the corner.

Under the Outboard Screw Conveyor Supports As the HMA moves outward axially along the screw conveyor (auger), it reaches the outboard conveyor support and bearing, which can develop a resistance to continued flow. Beyond that point, movement of the mix is achieved by pushing it outward using the influence of the last inboard screw flight's rotation.

Generally, problems rarely develop in this area with most easy-flowing mixes. However, stiffer, flow resistant mixes can cause a problem by gathering ahead of the screw bearing and flowing ahead under the paver's main frame, with some risk of mix segregation. In these cases, it is wise to use a short screw conveyor segment outside of the support and bearing to control and "power" the mix outside and away from the bearing. This will minimize the potential build-up and problems. The rule should be not to add the segment automatically unless it is necessary

Outer Edges of the Screed The most successful solution to eliminating segregation at the outer edges of the screed is maintaining a proper head of material at the screed's end gates (edger plates). This should be the same level as the rest of the conveyor—right at or about the top of the conveyor shaft. It is probably better to fault to a higher rather than lower head of material in this case, the key being to keep the level consistent. Continuous forward movement is important in keeping this balance.

➤➤*Function of Feeder (Flow) Gates*

With more modern pavers featuring self-regulating, proportional flight feeder/screw conveyor drives, the role of the feeder (flow) gates in regulating the level of material in the screw conveyor chamber is not always understood at the project level. These gates play a very important role in establishing the different capacities between the feeder and the screw conveyor, and they do not control total feeder/screw volume as was formerly experienced with older machines that had "on-off" feeder systems.

One of the more important tasks in minimizing segregation is to keep the proper head of material in the screw conveyor chamber. It is important to understand how the function and adjustment of the feeder gates contributes to maintaining that level. Their function can probably be best described by the following example.

> Assume that a single flight feeder is required to supply 150 tons per hour (TPH) to meet the demand of the screed for that half pavement width. Required capacity is generated by the speed of the flight feeder in combination with the open area under the feeder gate. It must be understood that the 150 TPH requirement can be provided at a lower speed and greater area (wider gate opening) or a higher speed and lesser area (lower gate opening). In either case, the demand for material is established by the combination of the screed width, layer thickness, and paving speed. The sensing device will establish the speed of the feeder to meet that demand, regardless of the gate opening, as long as that requirement is within the maximum production capacity of the feeder.
>
> The screw conveyor is linked to the flight feeder either by a roller chain or hydraulically. Its capacity, then, is the result of a combination of its shaft speed and the volume of material established by the area difference generated between its outer and inner diameters and the distance between its flights (its pitch).
>
> If a shortage of material is noticed at the edges of the screed (usually also noticed as too much material at the center of the screed), the screw conveyor's capacity must be increased to move more material to the outside. In this case, the feeder gates must be lowered. This will reduce the area under the gate and cause the feeder to speed up in order to continue to meet the 150 TPH demand. In so doing, however, the mechanical

or hydraulic linkage also causes the screw conveyor to speed up, thus increasing its relative capacity and providing more material to the end of the screed.

Similarly, too much material at the screed ends requires the gates to be raised to reduce the feeder/screw speed and diminish the screw conveyors' ability to move material to the screed edge.

➤➤Screed and Screw Conveyor Extensions

Self-extending screeds with trailing extenders are, by design, naturally self-feeding with most mixes and can generally be operated without screw conveyor extensions. A natural material flow is created as the screed is towed into the HMA supply, which is at rest on the paving surface. As the inside corner of the transition between the main screed and the trailing extender becomes filled with material, the natural action of adding more material in that area causes the mix to move outward to the screed's extremities, generating a "waterfall" effect.

Sometimes, an unnecessarily extended screw conveyor passing through this natural repose can only promote the risk of mix segregation as the screw flight rotates, particularly if it is operated at extra high speed. In these cases, screw conveyor extensions should only be used if the flow characteristics of the mix do not allow free flow, and the mix requires additional force and control to move it outward properly. The rule should be based on an end result criterion stating that "the paver material handling system should provide non-segregated material to the end-gate (edger plate) in sufficient quantities to provide for the variable pavement thickness requirements expected for that particular job." Screw conveyor extensions should only be required with self-extending screeds when such an end-result directed criterion cannot be met.

Analysis of Segregation

➤➤Pinpointing Segregation

All mixes and test samples, by nature, are subject to a certain degree of variation from the job mix formula. Limits on these variations, established by the agency based on its experience with mixes and sampling procedures, vary somewhat. However, when analyzing a segregated HMA mix, if a substantial amount of data is available, the agency can determine patterns in the mixture composition. Asphalt content and gradation of samples taken at strategic locations will furnish the information needed to pinpoint where segregation is occurring and to what extent.

To accomplish this, the results of asphalt content and aggregate gradation tests on a number of samples of HMA are used. Typically, the percent of material passing a selected critical sieve, usually the 2.36 mm (No. 8) or 2.00 mm (No. 10) sieve, is plotted on a graph against the asphalt content of that sample. Test results should be arranged according to the source of the samples, therefore, test results from samples taken at the HMA plant would be plotted separately from those originating at the roadway. This will facilitate interpretation of the test data and provide better information on where segregation occurs.

The graph indicates the percents passing the critical sieve on the horizontal axis, arranged in ascending order from the origin. The asphalt contents are arranged in ascending order from the origin on the vertical axis. The analysis is made using the asphalt content for each extraction

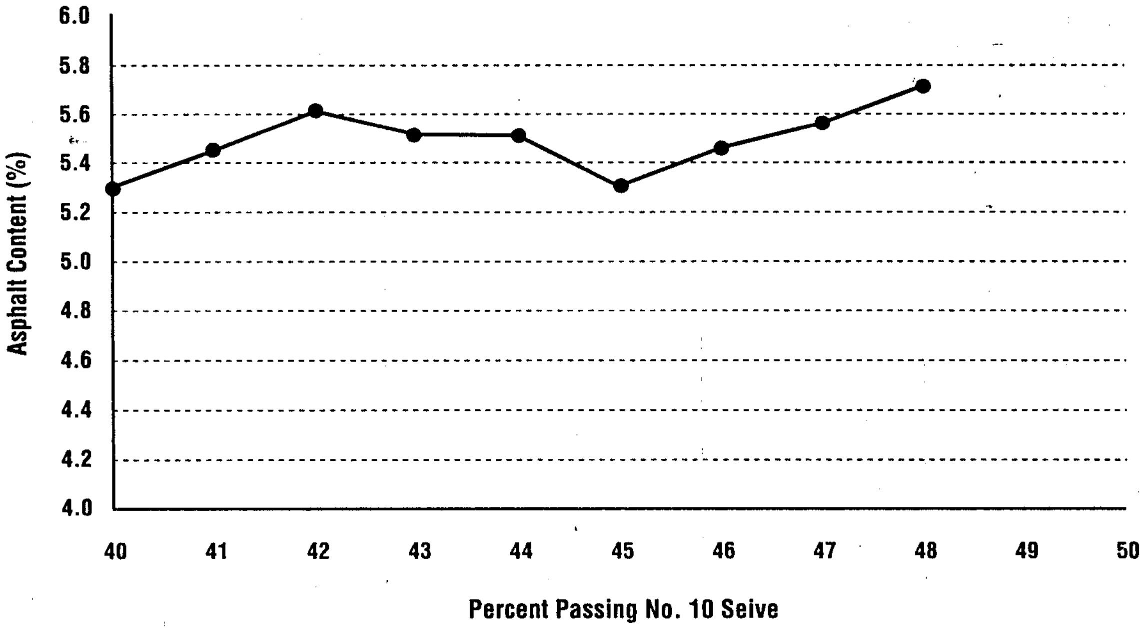

Figure 8.15 Material Which Segregated Before Mixing

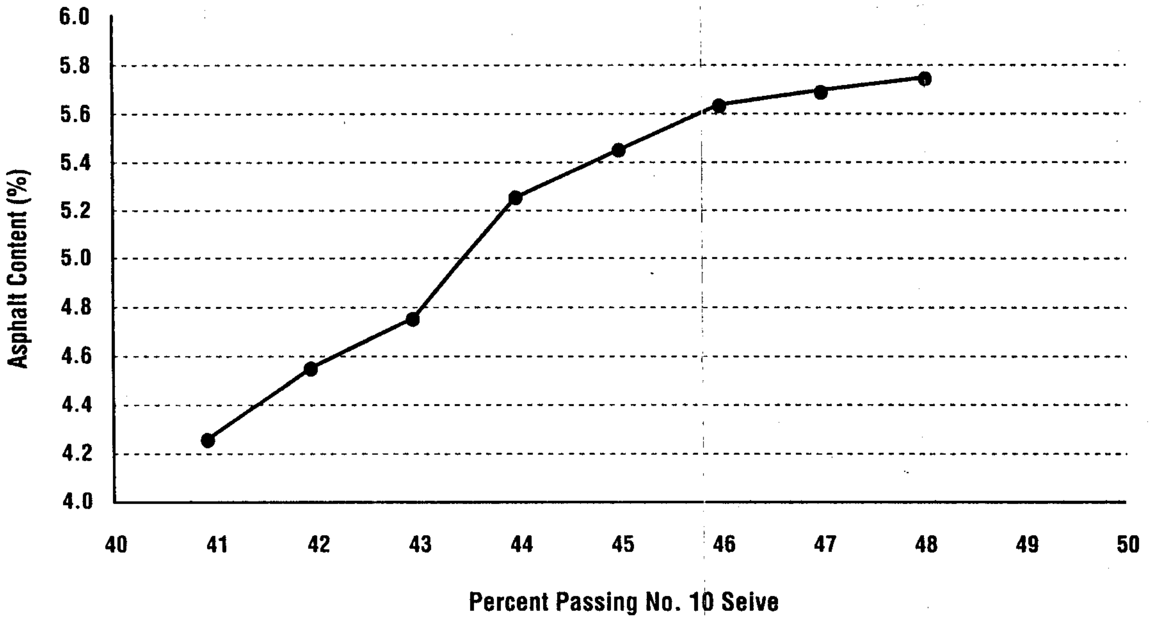

Figure 8.16 Material That Segregated After Mixing

plotted against its percentage passing the critical sieve. This procedure is followed for all of the samples from each selected location. The data is plotted as shown in Figure 8.15.

If the plot of these points from samples of segregated mix is roughly horizontal or nonlinear, the aggregate probably segregated before mixing as shown in Figure 8.15. This plot indicates that, for varying percents of material passing the 2.00 mm (No. 10) sieve, the amount of asphalt in the mix is erratic and has no trend, either upward or downward. To find the possible source of segregation in this case, the aggregate source, aggregate handling operation, cold bin loading and feeding, and drum or batch mixing operations should be checked.

If the plot of these points results in a relatively straight line, increasing in asphalt content as the percent passing the 2.00 mm (NO. 10) sieve increases, the HMA probably segregated after mixing. This is illustrated in Figure 8.16. It is normal for finer mixes to have a higher asphalt content. The ascending plot indicates that the finer particles got approximately the same coating of asphalt as they were being mixed, so that when the percent passing the 2.00 mm (No. 10) sieve increases, the asphalt content of the mix does also. If the finer particles got about the same coating, the proportion of coarse and fine material in the mixing facility was probably constant. In other words, the material was not segregated at that time. The places to look for causes of segregation in this case are the hot elevator, mixture storage and discharge facilities, truck loading operations, and paver operation.

Many of the poor practices occurring can be caught through a quick review of material handling of the finished product. However, sometimes a more thorough review of plant operations will be required to pinpoint the actual cause of segregation at this phase. If mineral aggregate handling and mixture handling procedures appear adequate, then this is a good time to review the mixture design and take appropriate action by perhaps modifying the job mix formula.

When the extraction of a base or intermediate course involves larger aggregate, the sample may be specially prepared to insure a representative sample. This procedure involves taking a large sample and separating it into plus 12.5 mm and minus 12.5 mm (+0.5 inch and -0.5 inch) portions. A ratio of these portions to the total sample is used to proportion the weight of the plus 12.5 mm and minus 12.5 mm material. Proportionate amounts of quartered samples are remixed for the extraction test, and this procedure assures the test sample will represent the mix.

➤➤Determining Segregation Level

Guidelines currently being used to identify segregation typically follow a standard format. It appears that most have been developed jointly by agency and industry in order to achieve the common goal. Methods of identification typically used are:

- Conducting preliminary field evaluations of existing projects exhibiting segregation, in order to determine and visually classify various levels of segregation.
- Developing a method to evaluate unacceptable segregation on construction projects.
- Verifying the test method on an active construction project.
- Developing an end product limit for segregation.

These field evaluations must be completed in order to clearly define achievable goals for all parties concerned. First, the evaluations give both parties the opportunity to walk the pavement together to see what a certain level of segregation looks like and to allow the agency to define what is an unacceptable level requiring corrective action. Second, the evaluations will allow the parties to determine if the various test methods used to measure segregation, measure the varying levels of segregation accurately. All written standards may include the following as minimums.

- Description of segregation
- Definitions of types and severity of segregation
- QC responsibilities of the contractor regarding segregation
- Investigations
- Dispute resolutions
- Acceptable corrective actions
- Basis of payment

Minimizing the likelihood of placing segregated mixture is the intent of all segregation standards. Remedial work, removal and replacement, and penalties are all methods of corrective action being enforced. However, when the pavement is deemed defective with regard to segregation, on the basis of visual inspection, the issue should be brought to the contractor's attention, in writing, as soon as possible. The actual severity and extent of segregation is typically reported at a later date. Understanding that severity levels exist for segregation is of paramount importance. Severity of segregation can be categorized as follows:

- Slight: Area where the mastic is in place between aggregate particles; however, there is slightly more coarse aggregate than in the surrounding acceptable mix.
- Medium: Area has significantly more coarse aggregate than the surrounding acceptable mat and usually exhibits some lack of surface mastic.
- Severe: Area appears very coarse in comparison to the surrounding acceptable mat, with stone against stone, and little or no mastic.

When severe segregation in any pavement course, or medium segregation in a surface course, is identified, a segregation standard should require the contractor to propose in writing the corrective action to be taken. Corrective actions vary between jobs and mixtures and will usually require actions similar to those described in earlier sections. Agencies normally review the corrective work proposal and consider the following actions to be acceptable for the types of segregation defined above.

- Slight: Typically will be accepted into the work.
- Medium: Generally left in place for lower layers; however, surface courses are typically subject to price adjustments, removal and replacement, or resurfacing, at the contractor's cost.
- Severe: Often the pavement is to be removed and replaced across the full lane or shoulder width in a workmanlike manner.

Work is typically suspended when the medium or severe level of segregation is identified. This allows the contractor the opportunity to address and take corrective action against any further segregation on the current project. Written plans, which could become contract documents, are usually submitted by the contractor to the agency before continuing paving operations.

Quantifying levels of segregation has become an issue in combating segregation. Many agencies use the following for quantifying segregation.

- Deviation from the approved job mix formula (JMF)
- Sand patch measurement
- Nuclear density gauge measurements
- Visual observation of non-uniform texture

Typical deviations allowed from approved JMF's for aggregate gradations are well established. When an extraction indicates a deviation greater than the established limit, segregation probably exists. The sand patch test (ASTM E965), when performed properly, demonstrates a mixture's ability to hold water. In this instance, the water is replaced with sand, which should cover a certain area when broomed around. The area covered will be less when placed over a severely segregated area. Some agencies use a nuclear density gauge to quantify segregation as follows:

> After rolling, three density readings are made at a selected transverse location at specified longitudinal distances from the truck exchange point. Excessively high or low values are thrown out, and the remaining values are averaged. Differences between average value and longitudinal values are calculated and recorded. Differences above maximum allowable are cause for shutdown because of segregation. Agencies may specify a maximum difference of 80 kilograms per cubic meter (5 lbs. per cubic foot) on base or binder course, and a maximum difference of 64 kilograms per cubic meter (4 lbs. per cubic foot) on a surface course as indicators for identifying these areas.

Given the financial impact to an agency's maintenance costs, these guidelines appropriately continue to be written and included in contract documents. Uniform and committed enforcement of segregation guidelines can substantially decrease placement of defective HMA pavements. Segregation is a defect that must be reduced to increase the life of HMA pavements.