Compaction Principles for Heavy-Duty HMA

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With the increasing use of large rock base courses and coarser mixtures to resist rutting in new and reconstructed asphalt pavements, proper compaction of Hot Mix Asphalt (HMA) is more important than ever.

Proper compaction requires confinement, space [mat thickness relative to aggregate size], elevated temperatures and compactive effort.

Confinement

Confinement is necessary to mechanically reduce the volume and increase the density of a mass of material. In HMA construction, confinement is provided by the underlying foundation, adjacent materials or structures, and by the internal friction and cohesion of the mixture. Regardless of whether a harsh or tender mixture is being placed, proper compaction cannot or will not be achieved if the underlying surface is yielding under the paver and rollers or sliding along the interface between old and new material.

Confinement is most difficult to achieve at free, unsupported edges. While much attention has been given to the best method to construct a longitudinal joint, problems with joint density have less to do with how the fresh material is placed and compacted against an existing lane than with poor compaction at the edges of the first pull.

Current research at the Texas Transportation Institute indicates that densities measured on the *hot* side of paving joints is comparable to that in interior sections of the mat, while the cold [unsupported] edge is considerably lower.

Approaches to compacting unsupported edges include:

▲ attaching end gates to the paver to act as slip forms,

▲ using small edge rollers immediately behind the paving screed,

▲ and using an attachment to a roller or motor grader to literally cut away a small strip of material after compaction has been completed.

Although wasteful, the latter approach is probably the most effective. It has been used frequently on projects that have a joint density requirement, such as those constructed under the Federal Aviation Administration (FAA) P-401 specification.

Space

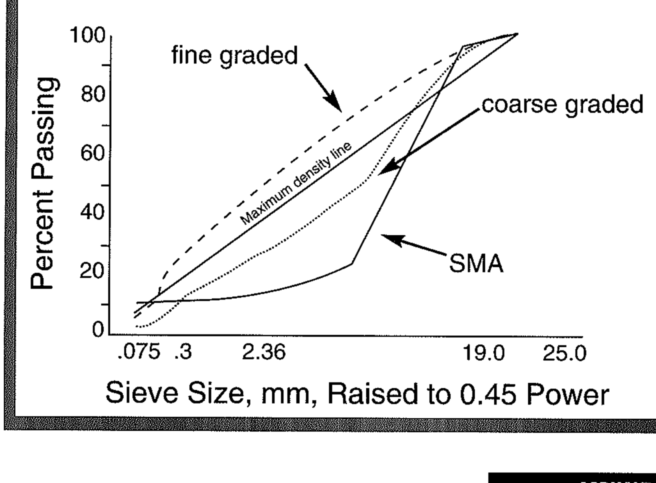
Space is a word that has not been used often when describing compaction, but it is a term that means having sufficient lift thickness to allow for particle reorientation during compaction of coarse mixtures. In the past, the rule-of-thumb was that lift thickness had to be at least two times the maximum aggregate size. That was appropriate for fine or continuously-graded mixtures, but in mixtures containing a much higher proportion of coarse aggregates, the 2:1 ratio does not allow enough room within the mat for moving the particles during compaction. Additional compaction applied on a mat with a 2:1 ratio only serves to fracture aggregate particles or break the mix apart.

For coarse-graded mixtures and stone matrix asphalts (SMAs), the minimum placement thickness should be at least three times the nominal maximum size rock, which is defined as one sieve size larger than the first sieve to retain more than 10 percent of the combined aggregates. *Table 1* shows the preferred range of compacted lift thickness that should be used for various mixture classifications.

Temperature

For any HMA mixture, compaction must occur within a temperature range in which the asphalt binder is sufficiently fluid. The aggregate particles can be reoriented while the binder is in a fluid state. As the HMA

Figure 1, HMA Gradation Plots



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cools after placement, the asphalt binder stiffens. Below a temperature of about 175°F (185°F when measured at the surface,) HMA using neat or unmodified asphalt binder cannot be compacted effectively.

As *Figure 2* shows, the amount of time available for compaction is highly dependent on the placement thickness, the temperature of the mixture during placement, and the temperature of the underlying surface.

Temperature has long been recognized as a critical compaction factor. It becomes even more important for HMA produced with modified asphalt binders. When modified asphalt binders are used, suppliers recommend that compaction should be completed before the mix temperature drops below 250°F. This effectively halves the time available when using neat asphalt binder.

Compactive Effort

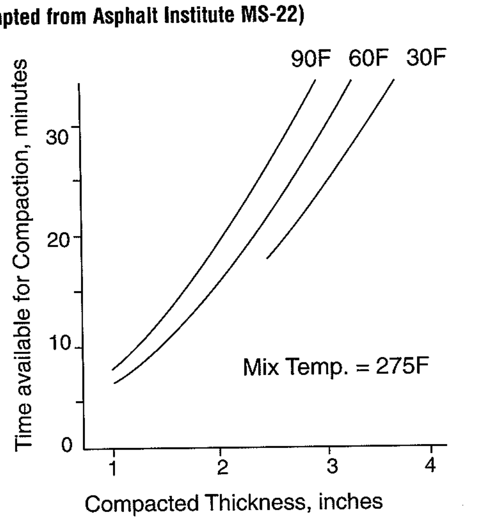
Compactive effort is applied first by the paver screed, then by rollers during placement of the HMA. The screed in the paving operation can have a decisive effect on the ability to compact HMA to the desired density level or to achieve the desired percentage of air voids for heavy-duty mixtures.

The weight of the screed provides most of the initial compactive effort during the paving operation. Since the screed is in contact with the mat while it is in its most workable state, operating the paver to maximize the screed's compactive effort can make the difference between success and failure during compaction—especially for mixtures containing modified asphalt placed in unfavorable weather conditions.

Maintaining slow, steady movement of the paving machine not only provides the greatest level of initial compaction, but also allows the roller operator to proceed without interruption under a more consistent set of conditions. This approach will also produce the smoothest, most uniform finished surface.

Coarse HMA mixtures with combined gradations that plot below the maximum density line (*Figure 1*) and other coarse-graded mixtures such as SMA and coarse matrix high binder (CMHB) should be compacted to between three and six percent air voids in place to sufficiently reduce permeability. This is stricter than the recommended target for fine or continuously graded mixtures (four to eight percent air voids) that are easier to compact than mixtures designed to resist rutting.

Figure 2, Time Available for Compaction
(adapted from Asphalt Institute MS-22)



Three Roller Categories

There are three roller categories used for HMA compaction—vibratory steel-wheeled rollers, pneumatic rollers, and steel-wheeled rollers. The vast majority of asphalt rollers being sold in the U.S. are vibratory steel-wheeled rollers because they are the most versatile.

They can be used for all aspects of HMA rolling—from *breakdown* or compaction rolling, which achieves the greatest change in density, to finish rolling where they operate in static mode to remove marks or indentations made by other rollers.

During the operation of a vibratory roller, a dynamic force is developed through the rotation of an eccentric mass around a shaft within the drum. This dynamic centrifugal force causes the drum to move up and down, generating an impact force. The vertical movement of the drum is referred to as *amplitude*, while the number of impacts delivered per unit of time is the *frequency*. These concepts are illustrated in *Figure 3*.

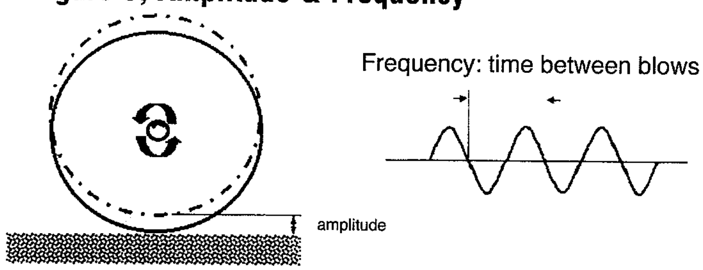
Generally, HMA vibratory rollers have amplitudes between 0.01 and 0.04 inches at frequencies ranging from 2,000 to 4,200 vibrations per minute (VPM). Rollers that can operate at very high frequencies cannot operate at high amplitude due to the bearings in the vibratory mechanism.

Particles in Motion

The principle behind vibratory compaction is the ability to provide a series of loads in rapid succession that causes the aggregate particles to move. When the particles are in motion, internal friction is greatly diminished, enabling the downward force from the static weight of the roller and the impact of the drum to pack the aggregate particles tightly together.

The most important features of a vibratory roller's compacting ability include its static linear load (expressed as pounds per lineal inch or PLI,) drum amplitude (inches) and frequency or vibrations per minute. Most heavy (greater than eight tons) vibratory rollers used for HMA compaction have different levels of amplitude and/or frequency. They are selected for specific jobsite conditions. Low amplitude applies when compacting layers less than two inches thick. High amplitude applies for thick lifts. For equipment that has variable frequency, the roller should be operated at the highest frequency level available for the selected amplitude.

Figure 3, Amplitude & Frequency



Other factors that are important when using vibratory rollers include roller speed, number of vibrating drums, drum diameter and drum width. When in vibratory mode, the roller should operate at a forward speed that produces a minimum of 8-to-10 impacts per foot—or between two and four miles per hour.

The drum diameter affects the contact area between the drum and the surface. A larger drum diameter increases the contact area and minimizes distortion of the fresh HMA during rolling.

Roller Weight and Dynamic Force

Among the important factors to consider when choosing a vibratory roller, particularly for heavy-duty HMA and thick HMA base courses, is the amount of force applied to the mixture by the static weight of the roller and the dynamic force caused by the drum striking the surface, as indicated by the roller amplitude.

Rut-resistant mixtures and thick HMA lifts require a high level of compactive effort to reorient the aggregate particles and compress the mixture. Consequently, a light roller operated at a high frequency can travel at a higher forward speed but require more passes to successfully compact a mixture than a heavier roller at a slightly lower frequency.

Pneumatic Rollers

Pneumatic rollers provide compactive force through smooth rubber tires. Depending on the size of the roller, seven or nine tires are staggered to cover the entire area under the roller on a single pass. Pneumatic rollers are useful for a variety of applications, ranging from compaction rolling on thick lifts to finish rolling. They are commonly used as intermediate rollers to supplement compaction provided by vibratory rollers.

Since the surface of the tire conforms to the underlying surface, pneumatic rollers will not bridge over points along the mat. The overlapping pneumatic tires create a kneading effect that reorients particles and seals the surface. This sometimes allows pneumatic rollers to achieve additional particle reorientation and compaction after vibratory rollers have been used.

As with vibratory and static steel-wheeled rollers, pneumatic rollers have various weights and sizes, which can be adjusted by adding or removing ballast.

For HMA compaction, wheel loads ranging 3000 to 7000 lbs. per tire are normally used. The tire pressure influences the contact area and the contact pressure. When operated as compaction rollers, pneumatic rollers carry a full ballast and the cold tire pressure is set at 70 psi or higher. For finish rolling, pneumatic rollers will operate at lower cold tire pressures—normally around 50 psi. Wide-based tires are also used for finish rolling.

Hot Tires and Skirts

Hot Mix Asphalt has a tendency to stick to the tires on pneumatic rollers, particularly if the contractor is using a modified asphalt binder. This can be minimized by heating and maintaining the tires at a temperature close to that of the HMA surface. In cool, windy conditions, adding skirts to the roller may minimize temperature loss and HMA pickup.

Static steel-wheeled rollers are most commonly used as finish rollers or as compaction rollers for thin HMA lifts.

Yes, the large rock base courses and coarse mixtures of today offer distinct advantages in economy, construction and performance, but they will continue to require the carefully crafted elements of proper compaction.▲

This article was first published by the Texas Hot Mix Asphalt Pavement Association. Gary Fitts is the Asphalt Institute's Field Engineer for Arizona, New Mexico, Oklahoma, and Texas.

Table 1, Minimum Recommended Lift Thickness

Nominal Maximum Aggregate Size, in.	Minimum Thickness, in.	Preferred Thickness Range, in.
0.375	1.0	1.25-1.75
0.5	1.5	1.75-2.5
0.75	2.25	2.5-3.75
1.0	3.0	3.0-5.0
1.5	4.5	4.5-6.0