

Final Report

**HOT IN-PLACE RECYCLING
LITERATURE REVIEW**

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Florida Department of Transportation

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INTRODUCTION

Hot In-Place Recycling (HIPR) has been promoted as a cost effective method of pavement rehabilitation, reportedly with many projects constructed successfully by other state agencies around the country. However, the experience of Florida Department of Transportation (FDOT) with this type of rehabilitation has been mixed, with some projects lasting only a few months before failure, and others lasting for more than eight years (1, 2). In order to establish how widespread and successful this technology is nationwide, a literature review was necessary. This review will provide FDOT with the necessary information to make accurate decisions regarding future use of this technology to ensure that the department's usage is appropriate and cost-effective.

HIPR is described as a procedure for recycling 100% of the existing asphalt pavement on-site by heating the surface, scarifying and/or milling to a specified depth, and placing and compacting with conventional paving equipment. HIPR may typically consist of one of three processes:

- Surface recycling
- Remixing
- Repaving

Surface recycling is the oldest HIPR process (3) and involves heating the surface with one or more heaters or pre-heaters that softens the existing pavement surface so that it can be scarified with tines or milled with a rotary milling head. The material is then windrowed, at which point rejuvenator is added, if desired. It is then picked up by a windrow device and deposited into a paver hopper and placed and compacted using conventional methods and equipment. The treatment depth ranges from $\frac{3}{4}$ to $1\frac{1}{2}$ inches as specified by the agency. The renewed surface is often overlaid with a Hot Mix Asphalt (HMA) course in a separate operation although it has been used as the final surface on some low traffic volume roadways (3).

Remixing is similar to the process for surface recycling except that virgin aggregate, new asphalt binder, rejuvenator, or HMA may be added as needed during the recycling operation. The additional materials are blended with the softened and windrowed existing pavement material to provide a homogeneous surface with improved characteristics. This process is useful when the existing pavement properties need to be modified, for instance, to enhance resistance to rutting, or improve durability and resistance to cracking. The remixing process can be accomplished in a single-stage, or multiple stages if additional layers or greater depth (up to about 3 inches) is desired.

Repaving involves placing a new overlay on the uncompacted HIPR layer so that the two layers are compacted at the same time. A single-pass method may be used in which the paver has two screed units, one for each layer. A multiple pass method may also be used in which there are two pavers in the paving train. One is used to place the HIPR layer, and the second follows immediately with the HMA overlay, after which both layers are compacted together.

Several advantages (3, 4, 5) for using an HIPR process are:

- Surface cracks are eliminated
- Rutting, shoving, and corrugations can be corrected
- Aged asphalt is rejuvenated
- Aggregate gradation and asphalt content can be modified
- Traffic interruption is minimal
- Haul costs are minimized
- Natural resources are conserved
- A thermal bond between longitudinal joints is created
- Current grade is maintained (for height restrictions)
- The need for shoulder buildup is eliminated

Although HIPR has several advantages, it has been met with some skepticism by highway agencies due to its inconsistent performance. A 2011 synthesis on in-place recycling (6) reveals that unsuccessful experiences are the greatest barrier to increased use of in-place recycling. Some past issues with HIPR may be related to poor project selection criteria, inadequate structure, or poor construction practices. A 1994 synthesis survey (5) indicated that 65% of state highway agencies had tried HIPR, but only 20 percent were using HIPR routinely. For that reason, a literature review is needed to determine what methods some agencies have found to work successfully when implementing or applying the HIPR technologies and areas that may be of concern.

LITERATURE REVIEW

As part of the literature review, information was solicited from selected state agencies and HIPR specifications being used by various agencies were reviewed. A literature review using the Transportation Research Information System (TRIS) database and other reported information was performed. Based on the reports found, there appears to have been a lot of interest in the HIPR process in the mid to late 1980s, but interest has decreased since then.

Survey

Several agencies were selected specifically by FDOT from which to obtain additional information. This information was sought in the form of a survey, and five of the agencies (Arkansas, Colorado, Kansas, North Carolina, and Texas) responded. The survey questions and agency responses are given below:

- a. How often is each state doing some form of hot in-place recycling on their state highway system? (Number of projects and approximate lane miles)

AR - Placed one trial project in early 1990s

CO - Placed 65 projects since 2000 totaling approximately 1800 lane miles

KS - Over 100 projects

NC - Placed approximately 1.4 million tons over 10 year period; last use of HIPR was in 2008

TX - One to two projects per year (20-30 lane miles)

- b. What has the typical performance of hot in-place recycling been in each state?

AR - N/A

CO - Approximately 9 years

KS - Typical life of 5-7 years

NC - Mixed performance (not necessarily due to HIPR but due to trying to transform surface mix into intermediate course)

TX - Mixed performance; a few perform satisfactorily, others age and rut prematurely

- c. What types of hot in-place recycling is each state doing?

AR - N/A

CO - All three types

KS - Surface recycling; one inch heater scarification; 1.5 and 2 inch HIPR incorporates heating and milling

NC - Remixing only

TX - All three types

- d. What guidelines do the states use in the selection of hot in-place recycling projects?

AR - N/A

CO - Use distress-related guideline similar to industry recommendations

KS - Good structural condition but with fatigue and transverse cracking

NC - Sufficient structure, but with oxidation, top-down, and reflective cracking

TX - Conduct condition survey to determine layer thickness, mix type, and penetration of recovered asphalt from existing pavement. Avoid pavements with multiple seal coats and geotextile fabric within depth to be recycled.

- e. How do states handle the pavement design aspect of hot in-place recycling?

AR - N/A

CO - Uses a layer coefficient from 0.35 to 0.44

KS - HIPR is considered structurally equivalent to the existing layer that will be replaced

NC - Use on projects that are structurally sufficient based on FWD testing

TX - Treat HIPR the same as a mill and fill operation

- f. How are other states typically handling the types of hot in-place recycling processes? What specifications do they use? Do the different processes have

separate specifications that are bid separately or are they bid competitively against each other?

AR - 2003 project was bid as alternate to cold mill/inlay. HIPR was not the successful alternate

CO - Uses separate specifications for each process; processes are bid separately

KS - HIPR includes mill heads and a paver to place material; typically do not add any admixture to HIPR

NC - Only remixing has been used

TX - Specifications incorporate all three types and they can bid against each other; bids may be pushed toward one process or another depending on what goes on top.

- g. Are other states considering hot in-place recycled asphalt to be equivalent to Superpave, and if so, what is the basis of their decision?

AR – No

CO - Yes, the mix being recycled is typically Superpave and any admixture used is also Superpave

KS - No

NC - HIPR is considered at least as good as the existing aged asphalt pavement

TX - Treated as the equivalent of a mill and fill project

- h. What are states doing for mix design verification prior to production? What types of acceptance testing and quality control measures are required?

AR - N/A

CO - Remixing process follows normal design procedures; in-place density and maximum specific gravity are used for quality control (QC) of surface recycling; for remixing and repaving processes, normal agency HMA QC tests are used.

KS - Contractor completes mix design to meet specifications. Depth checks are required, and density is controlled by a rolling procedure.

NC - Contractor completes mix design to meet specifications for mix type specified in plans. Acceptance based on depth, asphalt content, gradation, and density. PG binder grade verified randomly on recovered samples; penetration range of 40-90 dmm.

TX - Verifies contractor design; checks asphalt content, lab density, Hamburg results, and in-place air voids during production.

Project Selection Criteria

Not all of the HIPR processes treat each distress in the same manner, nor is the expected life of each process the same (3). Therefore, it is important that the existing structure is sufficiently analyzed made before a decision to perform HIPR on a project is made. In fact, the success of the HIPR process is extremely dependent on the existing conditions of

the pavement to be recycled (7). For example, if the pavement failure is caused by a structural issue, HIPR may mitigate the problem for a short while but the problem will not be eliminated. The HIPR process may be performed on pavements that have surface defects but are structurally sound (Figure 1).



FIGURE 1 Candidate Project for HIPR.

Another important consideration is the depth of the planned recycling. If the depth of the recycling is close to the interface of two layers, project construction could cause delamination between the layers. Moisture damage in the form of stripping could also be a serious issue for the HIPR layer if moisture is present in underlying layers and the resulting damage and moisture drainage issue is not corrected before performing the HIPR. The presence of moisture in pavement layers will also affect the penetration depth of heat energy into the pavement surface.

The depth of the recycling is also important because it affects the amount of energy needed to transfer heat to the desired depth. This may require additional preheating units (Figure 2), or for the progress of the paving train to be slowed so that heat can penetrate to the desired depth. If the paving train progresses faster than the ability of the heating units to transfer heat to the proper depth, the milled surface will have fractured aggregate rather than loosening the aggregate from softened asphalt binder. This may also create a slippage plane since the milled depth is greater than the heated depth, unless a tack coat is applied as part of the recycling operation. The lack of a tack coat after the milling operation may explain the early delamination and cracking on County Road 315 in Putnam County, Florida (1).

A project that has included geotextile fabrics in previous rehabilitation operations should be avoided if there is a chance the fabric may come in contact with, and become wrapped around, the milling head. The presence of rubber in the surface layer, from previous mix



FIGURE 2 Preheaters Used in the HIPR Process.

design or as a result of rubberized crack seals, or asphalt-rubber seal coats, may also create problems due to the rubber sticking to tires of the construction equipment. HIPR processes may also create excessive smoke and the recycled material and/or shoulder vegetation may catch fire due to the extreme heat used in the HIPR processes. For this reason, it is recommended that open-flame heating be prohibited.

The aggregate type used in previous HMA layers should also be considered when planning an HIPR project. Steel slag aggregate, for example, is unsuitable for HIPR due to its insulation effect and absorption characteristics, which results in poor heat transfer and generation of excess smoke (9).

Projects that have multiple crack seal applications should also be avoided. The heat from the HIPR process may set the crack seal material aflame and excess smoke will be generated. This may pose a safety issue if traffic is using an adjacent lane. The smoke also creates an insulating effect, which may limit depth of heated pavement.



FIGURE 3 Smoke and Flames from Crack Sealant.

Projects that have a patchwork of maintenance patches are not good candidates for HIPR. The consistency of materials and heat transfer in such pavements cannot be easily controlled or regulated during the HIPR process. Numerous pothole patches may also be indicative of other structural, environmental, or moisture problems that HIPR processes are not designed to correct.

Specifications

Several agency specifications were reviewed to determine what practices were used for mix design, the type(s) of equipment required, typical construction practices, and any Quality Acceptance/ Quality Control (QC/QA) tests typically used. Agency specifications are included in the Appendix of this report.

Most agencies have used either Method or End-Result type specifications for defining the work process, but a performance-based specification that incorporated a three-year warranty has also been used (2, 8). Florida is the only state that has used warranty specifications routinely for HIPR construction (6) although other agencies may use a combination of specifications.

Mix Design

Mix design procedures for HIPR are not well established (5) and the lack of a proven mix design method is listed as the greatest barrier to increased usage of in-place recycling by agencies (6). The lack of a consistent design method may account for some of the inconsistent performance reported. The goal of the recycling operation should be to provide a finished pavement that would perform the same as HMA. While most projects more than 15 years ago used viscosity and penetration of the binder to control the mixture proportions, the Superpave design procedure is becoming more widely used and binder

properties are related to performance grades. HIPR mix designs do not need to be substantially different from other accepted methods of design of recycled asphalt mixtures (5).

If the existing distress is from environmental aging of the binder, rejuvenators may be added to restore binder properties. If the existing pavement is unstable or rutting under traffic, additional aggregate may be added to reduce the total binder content and improve resistance to deformation. If the pavement lacks sufficient structure, admixture can be blended with the recycled material, or an overlay can be placed in a separate operation to increase the pavement thickness.

If moisture damage has occurred, an anti-stripping agent in the form of liquid additive or hydrated lime may be applied (Figure 4). The hydrated lime will also help prevent flare-ups if previous crack or joint fill operations have been used (9). If admixture or virgin aggregate is used in the process, a mix design is needed to ensure the resulting mix meets established specification requirements for conventional mixtures. Epps, et al. recommended that about five blends with various combinations of RAP, rejuvenator, virgin aggregate, and HMA admixture be developed and results compared to specification requirements (10). The number of blends needed depends on the size of the project and the type and severity of distress being corrected with the HIPR process (5, 10).



FIGURE 4 Addition of Hydrated Lime During HIPR Process.

To perform a mix design, samples of the existing pavement must be provided. The samples should be from a representative section of the project, or taken at random throughout the project. It is recommended that a representative section be milled to the depth to be recycled in order to supply sufficient material for mix design. This may be done by cold-milling, but additional fine aggregate particles will result that will not be generated with the hot-milling process of HIPR. Therefore, some slight variation in field gradation may be expected as compared to the laboratory mix design gradation. Use of hot-milling equipment to secure samples would be preferable, but may result in additional mobilization costs and construction delays while waiting for a mix design to be completed.

Asphalt binder content in an admixture, and/or incorporation of rejuvenators may be used to control the resulting penetration, viscosity, or paving grade of the completed recycled mixture. Mississippi DOT (MSDOT), for example, incorporated an admixture with 3% binder in the virgin HMA, and experimented with rejuvenator rates from 0 to 0.3 gal/yd² until a rate of 0.13 gal/yd² was determined to produce the desired binder properties for the combined blend of mixture (11). The average rejuvenation rate for Florida SR 471 was also 0.13 gal/yd² (2). If the existing pavement has high asphalt content, the amount of rejuvenator that can be added may be limited (9). The HIPR process itself will cause some oxidation of the asphalt binder and this hardening effect must be considered during mix design (9).

A MSDOT project (11) on Interstate 55 was one of the first to incorporate Superpave mix design procedures and use the Superpave Gyratory Compactor (SGC) to compact specimens to N_{Design} compaction level. Since the HIPR process resulted in a combined blend that consisted of about 80% recycled pavement (RAP), MSDOT anticipated the mixture would be harsher than normal and adjusted design air voids to 3% to allow for this possible difference.

Samples were also prepared for testing resistance to rutting using the Asphalt Pavement Analyzer (APA) at 120F (49C) for 7,500 cycles. The control mixes used for comparison were all virgin mixes prepared with various asphalt binder grades. The HIPR mixture performed comparably to the mixtures with modified asphalt (Figure 5).

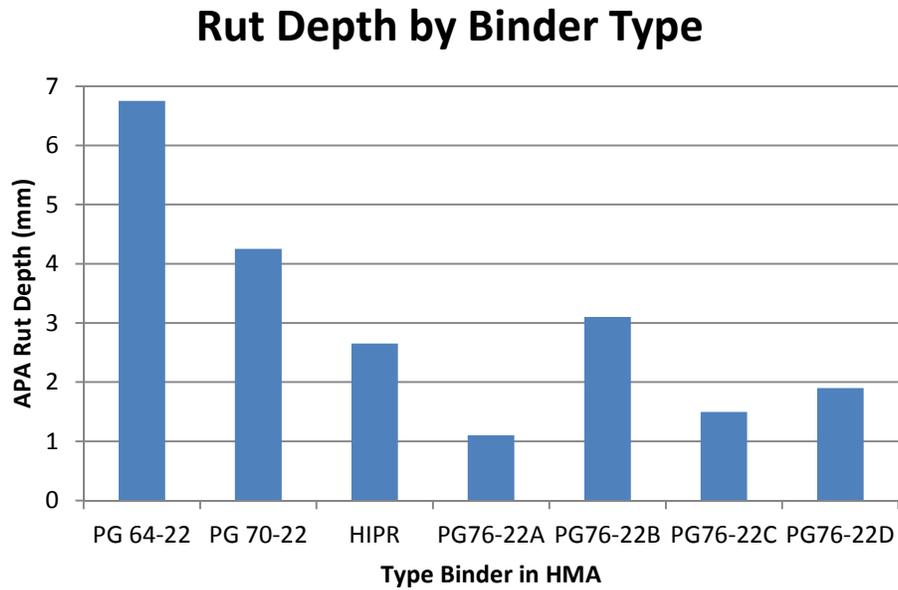


FIGURE 5 APA Rut Test Comparison by MSDOT (11).

Equipment

There are a variety of heaters and pre-heaters used in HIPR paving trains. However, open flame heaters are not recommended (8). Most of the processes use infrared or radiant heat, and penetration varies from one-inch to three inches in depth with the depth depending on the number of heaters and speed of the operation. This radiant heating panel produces almost 2,000°F of radiant heat in one minute, distributing more than 80,000 BTUs per square foot evenly throughout the entire heating panel (12).

One process uses hot air (heated to approximately 1100°F) produced in a diesel-fired furnace and blown onto the pavement through a manifold system. This process was able to recycle to a two-inch depth (11). The spent hot air is vacuumed back into the system and recycled as well. Another process has used a microwave heater in conjunction with cold milling to bring the recycled material to needed placement and compaction temperatures (5).

The rejuvenator feed rate is based on the unit weight of recycled pavement. For that reason, it should be controlled automatically based on the forward speed of the machine (5) and the volume of recycled material. The volume can be determined based on the speed of the machine, width of the windrow tunnel, and depth of material within the tunnel. Otherwise, too much or too little rejuvenator may be applied if the machine varies speed or if the depth of recycling varies.

Scarifying tines and a downward rotating milling head should be used to loosen the heated pavement material. This practice will help minimize fracturing the existing aggregate (8). Special precautions and adjustable scarifying teeth and milling head are necessary when working around manhole covers and utility valves. Extendable milling

heads are available that can cover widths of 10 to 16 feet (2). Although some mixing occurs during the scarifying and milling process, a pugmill is needed to ensure complete mixing of the recycled material and any rejuvenator, virgin aggregate, or HMA admixture (5).

Construction

Productivity is largely controlled by the amount of heat energy needed to penetrate to the desired depth. This is affected by the ambient temperature, moisture in the underlying layers, weather conditions, and whether additional aggregate, hot mix, or other additives are to be incorporated into the HIPR process. The use of additional heating units or multi-stage operations may also improve productivity. Typical speed of the paving train on one project was about 6 to 16 feet per minute (8). MSDOT was able to recycle only about 4,335 yd² daily (10), which amounts to about 0.6 lane miles per day although recycling of up to 1.7 lane miles per day have been reported (5).

One of the suggested advantages of HIPR is an improved bond between the recycled mix and the existing pavement due to the heat penetration into the existing pavement. However, bond strength tests by FDOT showed that cores from the HIPR project had very similar bond strength results as for a conventional HMA project (1).

The HIPR process can be used to correct slight deviations in cross-slope. However, adjustments in cross-slope may also require raising or lowering the longitudinal profile grade to maintain adequate material in the paver hopper. If the paver screed height is not adjusted in time, excess material could clog up the pugmill mixer in the paving train and shut down the operation (11). Likewise, if the existing cross-slope is less than 1.5%, the amount of admixture needed may be increased, or the desired cross-slope reduced.

The long paving train for HIPR is not practical for short areas or sharp curves such as for intersection radii since some pieces of the HIPR equipment may be up to 60 feet long (13). HMA should be used to overlay hard to reach areas and the HMA should be placed first in order to avoid longitudinal joints.

MSDOT (11) required an ambient temperature of 45F in order to begin HIPR construction. They also found that when the temperature of the mix in the paver hopper fell below about 265°F, a minor amount of uncoated aggregate could be seen. Temperatures of the existing pavement surface on a Florida project reached 530°F (1) before remixing and paving, but the mix temperature immediately behind the paver screed was typically around 240°F. A thermal image from SR 542 in Washington shows very consistent temperatures across the mat (13). The temperature behind the paver screed ranged from 195°F to 240°F. The surface temperature should largely be a function of the depth to be recycled, the number of heaters provided, the speed of the paving train, and the amount of oxidation of the existing pavement prior to recycling.

QA/QC Testing

There is also a lack of consistent QA/QC procedures (5) from agency to agency and even from one HIPR process to another.

One of the goals of most HIPR projects is to rejuvenate the oxidized asphalt binder in the existing pavement. This is accomplished by adding light rejuvenating oils, or by using a lower performance grade binder in HMA that is blended as an admixture in the recycled material. The combined final mixture is extracted and the asphalt binder recovered to determine the penetration value by AASHTO T 49.

The Ministry of Transportation in Ontario (MTO) has reported that an acceptable range of penetration values is 50-80 dmm (8), and North Carolina requires a penetration range of 40-90 dmm (14). The average increase in their penetration values has ranged from 18 to 45 units when before-and-after comparisons have been made. FDOT has experienced wide ranges in recovered penetration values (23 to 72), but it was not known if the variation actually represented in-place material or if it was due to fluctuations in the application of rejuvenator (1). Florida's SR 471 project had recovered penetration values that ranged from 39 to 66 dmm (2).

The viscosity of recovered binder, or performance grade, may also be used as a quality control tool. The mean value of viscosity, for example, should be controlled relatively closely although considerable variation throughout the project may be encountered, especially where patching is encountered. Failure to check recovered binder properties of the final mix may permit premature hardening of the binder by overheating or excessively soft binders by adding too much rejuvenator, which will adversely affect performance (5). However, there may also be large variations in recovered viscosity, depending on the variability of in-place material and the consistency of rejuvenator application and remixing. FDOT experienced a viscosity range of 2,804 to 45,970 poises (1) on its SR 19 project.

The control of air voids is just as important for HIPR projects as for conventional HMA projects. Fine aggregate, or an admixture low in asphalt content can be used to increase air voids. To reduce air voids, a rejuvenator may be added or an admixture with high asphalt binder content may be used. WSDOT found that HIPR mixtures could be compacted to higher density values without the normal fear of increasing rutting susceptibility (13).

MSDOT requires laboratory testing on a daily basis for asphalt content and gradation of the virgin HMA and maximum and bulk specific gravity of the final recycled mixture (11). The contractor is typically required to furnish a properly equipped field laboratory with the testing equipment necessary to monitor/verify quality of the produced mixture. Samples of plant-produced mixture were compacted with a Superpave Gyratory Compactor (SGC) and field adjustments were made as necessary to keep air void levels between 3 and 4 percent. A minimum of 92 percent of the maximum specific gravity was used to control field density. Washington Department of Transportation (WSDOT)

compared a normal distribution curve of density tests for both HIPR and HMA construction on SR 542 (13) and found that HIPR mixtures could be expected to achieve comparable density to HMA.

MSDOT required a maximum smoothness profile of 17 in/mi when testing with a California profilograph with a 5 mm blanking band (11). Areas which failed to meet density or smoothness specifications were required to be reworked without additional rejuvenator or admixture. About 10 percent of the project area had to be reworked due to failure to meet either density or smoothness requirements. Most of the problems with construction were determined to be operational in nature. FDOT also found there was virtually no improvement in smoothness when comparing International Roughness Index (IRI) values before and after construction (1).

FDOT based acceptance on asphalt content, gradation, density, and smoothness. The gradation on one project was consistently finer than the mix design target value but the values obtained were likely a better reflection of the actual in-place gradation than the samples taken for mix design. Variability of gradation results was not excessive (1). On another project, the gradation was consistent with the target mix design value with the exception that the percent passing the No. 200 sieve averaged 1.5% higher. If the pavement is not heated sufficiently to the desired depth, the milling operation becomes more like a cold-milling process which generates more fines than the hot-mill process. This may explain why the percent passing the No. 200 sieve may be higher on some projects. FDOT suggested that the excess fines from cold-milling may also explain the delamination between layers (1).

Binder results of the FDOT project on CR 315 averaged 0.6% less than the target value and four of seven tests were less than the acceptable tolerance (1). However, on SR 19, all individual results were within tolerance. Only 2 percent HMA admixture (based on estimated total mix weight) and 0.04 percent rejuvenator (based on weight of binder) were added on CR 315, so the deviation in binder content may have been a difference in the sampling of material for mix design compared to actual in-place mixture for the depth being restored. Some of the variation may also be a reflection in thickness of the recycled mat which varied from 1.13 to 1.94 inches. It has been shown that milling the heated material makes it more difficult to delineate the layer interface between surface and underlying structure as compared to cold-milling.

Performance

Performance of HIPR projects has generally been inconsistent, with some projects failing almost immediately and other projects lasting comparable to HMA overlay projects. In Ontario, Canada, HIPR pavements were observed to perform comparably to conventional rehabilitated pavements (8). The MSDOT project (8) was a previous HIPR project that had been in place for only 6 years before being recycled again. And one project in Florida began to crack and delaminate within a couple weeks of construction. Delamination spread to more than 50% of the project so it was milled and resurfaced with HMA (1).

One agency noted that the surface of HIPR projects tended to oxidize quicker than HMA projects, and that raveling tended to be more prevalent. Raveling is also encountered at startup/transverse joints, possibly due to overheating or under-heating or not introducing enough HMA admixture (5).

In a survey of western states (7) it was noted that cracks in the existing pavement tended to reflect through within six months. However, this distress may be a result of stripping in underlying layers that were unable to be repaired using only a recycling operation.

FDOT recommended (1) that a warranty should be part of any HIPR contract in order to ensure against early failures. On a 2002 project in Sumter County, Florida (SR 471), a three-year warranty with criteria for rutting, rideability, cracking, raveling, delamination, potholes, slippage, and segregated areas was required (2). The contractor was not held liable for:

- Deficient pavement thickness based on pavement design,
- Traffic loading exceeding 25% of that used for pavement design analysis,
- Deficiencies due to underlying asphalt, base, and subgrade layers, or
- Deficiencies due to work by a third party.

A list of distresses and threshold limits included in the warranty specification is given in Table 4.

Figure 6 shows a comparison of FDOT SR 471 before recycling and the condition of the roadway after seven years of performance.

Agency response to life-cycle performance (6) indicates that IRI roughness can be expected to increase at a rate of 15 in/mi annually, and fatigue cracking increases at about 240 ft²/mi while longitudinal cracking increases at about 2% annually.

Table 4 - Thresholds and Remedial Actions for Distress Types (2).

Type of Distress	Type of Survey	Threshold Level for Each Lot (0.1 Mile) per lane	Remedial Action
Rutting	Any Survey	Depth > 0.25 inch	Remove and replace the distressed LOT(s) to the full distressed depth and full lane width.
		Depth ≤ 0.25 inch	None required.
Rideability	Any Survey	RN < 3.70	Remove and replace the distressed LOT(s) to the full distressed area(s) and full lane width.
Cracking	Any Survey	Cracking > 1/8 inch (Class 1B), accumulative cracking length > 30 feet	Remove and replace the distressed LOT(s) to the full distressed depth and full lane width.
Raveling, delamination, and other disintegrated areas affecting the friction course	Intermediate Survey	Underlying layer exposed, individual length > 10 feet	Remove and replace the distressed area(s) to the full distressed depth and full lane width or patch the distressed area(s).
		Underlying layer exposed, individual length < 10 feet	Patch the distressed area(s) and remove and replace the distressed area(s) to the full distressed depth and full lane width prior to the final survey.
	Final Survey	Observation by Engineer	Replace the distressed areas (including all patches) and extend 50 feet at both ends at full lane width.
Potholes, slippage area(s), segregated area(s) and other disintegrated areas.	Any Survey	Observation by Engineer	Remove and replace the distressed area(s) to 150% of the area(s) or temporarily patch the distressed area(s) and remove and replace the distressed area(s) to 150% of the area(s) prior to the final survey.



FIGURE 6 HIPR Project Before Recycling (a) and Seven Years Later (b). (2)

Cost - Benefit

Denver's Public Works Department uses the HIPR repaving process to recycle the existing pavement to a depth of one-inch and overlay it with a 1-inch new HMA layer. The Street Maintenance Division estimates the agency has saved more than \$5 million over a five year period (30 percent savings) compared to traditional mill and 2-inch overlay operations (15).

MSDOT determined the cost of recycling to a 2-inch depth with the HIPR process, including rejuvenator and HMA admixture, was \$5.48/yd² (1997 prices) which was about 12% higher than conventional 2-inch mill and fill scenarios (11). The higher cost for HIPR was likely influenced by having to negotiate prices with the contractor through a supplemental agreement in order to try the HIPR process.

Environmental benefits are also realized with the use of HIPR. For example, St. Louis County, Minnesota, said this technique will eliminate more than 2,000 truck trips and save 7,000 gallons of diesel fuel on the Rice Lake Road project (16). Likewise, a Greenville, Mississippi project reported having an 80% smaller carbon footprint than a stand-alone asphalt plant, and the HIPR process eliminated the trucking of more than 30,000 tons of millings and asphalt on one job alone. That equates to more than 2,000 truckloads of resources (17).

In 2001, 1.5-inch HIPR projects using the remixing process cost FDOT \$2.30 to \$4.21/square yard compared to conventional 1.5-inch mill and fill HMA project cost of \$4.45 to \$4.75/square yard (1). This represents a savings ranging from 11 to 48%. The Washington DOT (WSDOT) also experienced a savings of 15-35% for the HIPR process as compared to conventional mill-and-fill HMA (7, 13).

Cost comparisons should carefully consider the resulting mix. Many of the earlier HIPR recycled projects consisted of mixtures designed with the Marshall method, whereas the current HMA mixes often used for comparison are designed with Superpave criteria. In many cases, the Superpave criteria requires better quality materials. Very little life-cycle

cost information has been collected, and further long-term evaluation of HIPR projects is needed.

DISCUSSION

HIPR has experienced limited acceptance due to inconsistency in performance. One reason for unsatisfactory performance may be that most mix design procedures are outdated and still require Marshall procedures and viscosity/penetration binder testing. Georgia Department of Transportation specifies that the Superpave Dynamic Shear Rheometer be used for binder testing and that the gyratory compactor be used for mix design and project quality control information on HIPR projects (18). Existing pavement mixes may lack the aggregate structure of typical Superpave mixes as well, but this may be corrected somewhat by adding additional virgin aggregate to provide the necessary stability.

However, in order for any resurfacing/ reconstruction to be successful, a thorough analysis of the existing pavement distresses and their causes is essential. Neither the HIPR process nor HMA construction should be expected to cure pavement problems without determination of the source of the problems. For that reason, several key items are presented below that may be used as a guide to determine whether HIPR should be considered for a particular project. Project selection criteria include:

- Must have stable structural foundation
- Check existing pavement to planned recycling depth
 - Avoid geotextile fabrics
 - Determine aggregate types and properties of existing pavement
 - Resolve moisture-related issues
- Avoid projects with multiple crack seal coats
- Avoid projects with patchwork repairs or maintenance
- Determine the type of HIPR process needed
 - Surface recycling only
 - Addition of admixture and/or rejuvenators
 - Recycling of existing layer and overlay

Table 5 gives a summary of typical pavements that may and may not be acceptable for HIPR processes.

TABLE 5 Recommendations for HIPR (7)

<u>HIPR Not Recommended:</u>	<u>HIPR Recommended:</u>
Thin Pavements	Existing Pavement is Rutted (not severely)
Base/Subgrade Failures	Existing Pavement is Aged (not severely)
Drainage Improvements are Required	Existing Pavement is Stripped (not severely)
Irregular or Frequent Patching	Minor Thermal Cracking
Narrow Roads	Ideal candidate is a pavement that is not too old and not excessively oxidized
Numerous Obstructions	
Multiple Surface Treatments Present	
Open-Graded Friction Course	
Severely Stripped or Delaminated	

CONCLUSIONS

- The success of the HIPR process is extremely dependent on the existing condition of the pavement to be recycled.
- Potential projects may have surficial defects such as fatigue or block cracking but should be structurally sound.
- Open flame heating should not be allowed.
- Rejuvenator feed rate should be based on unit weight of the RAP by determining forward speed of the machine, width of the windrow tunnel, and depth of RAP within the tunnel.
- Penetration, viscosity, or PG determination of recovered binder should be included in quality control testing to ensure the recycled mixture is not overheated and that excessive rejuvenator is not used.
- The surface temperature of the heated pavement should be a factor of the depth being recycled, but temperatures have reached 530°F in order to provide heat penetration to the depth needed.
- Existing pavements with high asphalt content may limit the amount of rejuvenator that can be used.
- Some oxidation of the asphalt binder will occur during the HIPR process, and this hardening effect must be considered during the mix design stage.
- The Superpave binder grading system and mix design procedures can reasonably be used to design and establish control parameters for improving construction quality.
- Long-term evaluation of HIPR projects is needed in order to better determine representative life cycle costs using current HIPR technology. For cost/benefit analysis, in-place Superpave mixtures should be used for HIPR recycling to compare to the performance of Superpave HMA mixtures.
- Milling the heated material makes it more difficult to delineate the layer interface between the surface and underlying structure as compared to cold-milling.
- Bond strength at the layer interface of HIPR projects is similar to bond strength of conventional HMA overlays.

REFERENCES

1. Sholar, G., J. Musselman, G. Page, P. Upshaw, and H. Moseley, *Evaluation of Two Hot-In-Place Recycling Projects*, FDOT Research Report FL/DOT/SMO/02-455, Gainesville, FL, July, 2002.
2. Sholar, G., J. Musselman, G. Page, and H. Moseley, *Resurfacing of SR-471 Using the Hot-In-Place Recycling Process*, FDOT Research Report FL/DOT/SMO/04-472, Gainesville, FL, June, 2004.
3. "Basic Asphalt Recycling Manual," Asphalt Recycling and Reclaiming Association/Federal Highway Administration, 2001.
4. Kandhal, P. S., and R. Mallick, *Pavement Recycling Guidelines for State and Local Governments*, FHWA publication FHWA-SA-98-042, Washington, DC, 1997.
5. Button, J, D. Little, and C. Estakhri, *Hot In-Place Recycling of Asphalt Concrete*, Synthesis of Highway Practice 193, NCHRP/TRB, Washington, DC. 1994.
6. Stroup-Gardiner, M., "Recycling and Reclamation of Asphalt Pavements Using In-Place Methods", NCHRP Synthesis 421, NCHRP/TRB, Washington, DC. 2011.
7. Pierce, L., *Hot In-Place Recycling: SR-97 West Wapato Road to Lateral A Road (SB)*, Washington Department of Transportation, Report No. WA-RD 408.1, Olympia, Washington. 1996.
8. Kazmierowski, T., P. Marks, and S. Lee, *Ten Year Performance Review of In-Situ Hot Mix Recycling in Ontario*, Paper presented at TRB Annual Meeting, Washington, DC. 1999.
9. Fyvie, K. and J. Valkenburg, *Hot In-Place Recycling of Runway 15-33 Prince George Airport, B.C. – A Case Study*, Proceedings 34th Annual Conference of Canadian Technical Asphalt Association, Volume XXXIV, November, 1989. pp. 258-277.
10. Epps, J., D. Little, R. Holmgreen, and R. Terrell, *Guidelines for Recycling Pavement Materials*, NCHRP Report 224, NCHRP/TRB, Washington, DC. 1980.
11. Crawley, A., *Innovative Hot In-Place Recycling of Hot-Mix Asphalt Pavement in Mississippi*, TRR 1654, TRB/NRC, Washington, DC, 1999. Pp 36-42.
12. "Hot, Cold, and Green (and the 3Es) In-place pavement recycling meets a variety of needs," Better Roads, Vol. 81, No. 2, February, 2011.
13. Russell, M., J. Uhlmeier, J. DeVol, C. Johnson, and J. Weston, *Evaluation of Hot In-Place Recycle*, Washington Department of Transportation, Report No. WA-RD 738.1, Olympia, Washington. June, 2010.
14. Standard Specifications for Roads and Structures, Section 663, NCDOT. Raleigh, NC. 2006.
15. "Hot In-Place Recycling Key to Denver's Street Maintenance," from website: <http://forconstructionpros.com/online/printer.jsp?id=2496>, posted January 11, 2011.
16. "New Paving Technique on Rice Lake Road" WDIO Eyewitness News, Duluth, MN, Aug. 15, 2011. From website: <http://www.wdio.com/article/stories/S2242070.shtml?cat=0>

17. “Greenville goes green- Miss. town shows how new asphalt recycling process saves time, money,” Roads and Bridges, Vol 49, No. 4, April, 2011.
18. Georgia Department of Transportation, Standard Specifications, Section 403. From website: <http://dot.ga.gov/doingbusiness/TheSource/specs/ss403.pdf> on September 2, 2011.

APPENDIX

COLORADO HOT IN-PLACE RECYCLING SPECIFICATION

**SECTION 405
HEATING AND SCARIFYING
TREATMENT**

DESCRIPTION

405.01 This work consists of recycling the top portion of the existing asphalt pavement as shown in the Contract, by cleaning, heating, scarifying, redistributing, re-leveling, compacting, and rejuvenating the existing asphaltic material.

MATERIALS

405.02 Asphalt rejuvenating agent shall meet the requirements of subsection 702.04.

CONSTRUCTION REQUIREMENTS

405.03 Weather limitations shall be as provided in subsection 401.07. Prior to commencing heating and scarifying operations, the pavement shall be cleaned of all loose material. Power brooms shall be supplemented by hand brooming and use of other tools as required to bring the surface to a clean, suitable condition free of deleterious material.

Equipment used to heat and scarify the asphalt surface shall meet the following requirements:

- (1) Capable of uniformly applying heat under totally insulated, enclosed hoods to produce radiant heat.
- (2) Self-propelled and capable of scarifying to the depth specified.
- (3) Capable of covering a minimum of 750 square yards per hour while heating the existing surface to the extent that it will be remixed by the scarifiers to a depth not less than specified.

The heating operation shall extend at least 4 inches beyond the width of scarifying on both sides. When a pass is made adjacent to a previously placed mat, the longitudinal seam shall extend at least 2 inches into the previously placed mat. The temperature of the scarified material shall be between 200 and 300 °F when measured immediately behind the scarifier. The scarified material shall be distributed and leveled by a paving machine. The paving machine shall be capable of screeding the full width of the scarified material to produce a uniform cross section as shown in the Contract.

While the scarified material is still hot and before it is placed by the paving machine, an application of asphalt rejuvenating agent shall be applied as specified.

The asphalt surface shall be compacted immediately after it has been distributed and leveled, and while it is still workable. Two rollers shall be used to compact the scarified material. A steel wheel roller shall be used first to provide breakdown

rolling, followed by a pneumatic tire roller with a minimum weight of 12 tons, to complete compaction to 92 to 96 percent of maximum theoretical density. When the mixture surface temperature falls below 165 °F, no further compaction effort shall be done unless approved. A minimum of 24 hours shall elapse before an asphalt pavement overlay is applied to the scarified pavement.

The weight per cubic foot of the existing asphalt surface shall be determined in accordance with AASHTO T 166. Scarification depth will be acceptable when the moving average of a minimum of three consecutive random tests per hour indicates that the required amount per square foot, based on the weight per cubic foot of the existing asphalt surface, has been scarified. Testing shall be performed by the Contractor in lots of three per hour, or as often as necessary to maintain process control.

The longitudinal surface smoothness of the roadway prior to and after heating and scarifying shall be tested in accordance with subsection 105.07(f).

METHOD OF MEASUREMENT

405.04 Heating and scarifying treatment will be measured by the square yard of work completed and accepted.

BASIS OF PAYMENT

405.05 The accepted quantities of heating and scarifying treatment will be paid at the contract unit price per square yard for heating and scarifying treatment, and shall include cleaning, heating, scarifying, redistributing, re-leveling, and compacting the existing asphalt surfacing.

Payment will be made under:

Pay Item	Pay Unit
Heating and Scarifying Treatment	Square Yard

Asphalt rejuvenating agent will be measured and paid for in accordance with Section 411.

FLORIDA HOT IN-PLACE RECYCLING SPECIFICATION

**REWORKED ASPHALT CONCRETE.
(REV 8-9-11)****SECTION 324 REWORKED ASPHALT CONCRETE PAVEMENT****324-1 Description.**

Construct a reworked asphalt pavement layer using milling and plant-produced hot-mix asphalt or the hot-in-place recycling process, as specified in this Section. The applicable requirements of Sections 300, 320, 327, 330, 334 and 337 apply to the reworked asphalt layer, as noted herein.

324-2 Hot Mix Asphalt Materials.

324-2.1 General Requirements: The following materials requirements apply only to plant-produced hot-mix asphalt for the reworked asphalt pavement layer.

324-2.2 Asphalt Binder or Recycling Agents: Meet the requirements of 916. If the reworked layer is the final surface, use a PG 67-22 binder meeting the requirements of Section 916 or an asphalt rubber binder meeting the requirements of Section 336.

324-2.3 Aggregate: Meet the requirements of Section 901 for coarse aggregate and Section 902 for fine aggregate.

324-2.4 Reclaimed Asphalt Pavement (RAP) Material: RAP may be used as a component of the asphalt mixture with no limit subject to the following requirements:

1. Assume full responsibility for the design, production and construction of asphalt mixes which incorporate RAP as a component material.
2. Provide stockpiled RAP material that is reasonably consistent in characteristics and contains no aggregate particles which are soft or conglomerates of fines.

324-2.5 Mix Design Requirements: If the reworked layer is the final surface, RAP from this project may be used in the mix design with no limit provided any virgin aggregate that is used in the mix design is either granite or Oolitic limestone.

324-3 General Composition of Mixture.

Compact the mixture in the laboratory using a Superpave gyratory compactor in accordance with AASHTO T 312-08. Utilize a design number of gyrations of either 50 or 75. The design air void content shall be within the range of 3.5 to 4.5%. The minimum voids in the mineral aggregate (VMA) shall be 12.0%. The minimum effective binder content shall be 4.5%. Utilize FM 1-T 209 for determination of the mixture's maximum specific gravity for air void determination. Assure that the recovered binder from the compacted mix will have a penetration value within the range of 40 - 80 dmm when tested in accordance with AASHTO T 49 or have a recovered viscosity within the range of 5,000 – 15,000 Poises when tested in accordance with AASHTO T 202. Furnish a copy of the mix design to the Engineer prior to any paving work. During production, the Contractor may revise the mix design provided the previous design requirements are met. Submit mix design changes to the Engineer for informational purposes only.

324-4 Construction.

324-4.1 General Requirements: Prior to commencing construction operations, repair all defective portions of the existing pavement as indicated in the plans. The minimum ambient temperature required for operations is 45°F. Clean the pavement such that it is reasonably free from loose materials, sand, dirt, caked clay and other deleterious substances. Remove and dispose of all reflective pavement markers. Remove thermoplastic striping prior to hot-in-place recycling operations.

324-4.2 Milling: Use the cold milling process per Section 327 to remove the upper layer(s) of asphalt above the reworked layer, if shown in the plans. Use cold milling, hot milling or hot scarifying to remove the existing reworked layer for recycling.

324-4.3 Bonding of Pavement Layers: Construct a pavement in such a manner to assure that the layers are adequately bonded.

324-4.4 Compaction: Select the compaction equipment and rolling sequences necessary to meet the density specifications as set forth below. Complete all compaction operations before the pavement surface temperature drops to 150°F.

324-4.5 Additional Requirements: When construction includes the paving of adjacent shoulders (equal to or less than 5 feet wide), the layer thickness for the top pavement layer and shoulder must be the same and paved in a single pass, unless called for differently in the Contract Documents.

324-5 Contractor's Process Control.

324-5.1 General: Utilize a Process Control System that will provide assurance that all materials and products furnished to the Department conform to the Contract requirements, and will meet the performance requirements, as outlined below. Document all Process Control procedures, inspections, and tests and make that information available for review by the Department throughout the life of the Contract. Transfer ownership of these documents to the Department at the end of the project.

Utilize a process control plan that contains the following as a minimum:

- a. Determination of asphalt binder content, maximum specific gravity, air void content, gradation, and asphalt binder viscosity or penetration – minimum frequency of once per day.
- b. Depth determination (uncompacted mix) - once per 100 feet.
- c. Determination of pavement thickness (roadway cores) - per 324-5.7.
- d. Density determination (roadway cores) - one core per 1,000 feet.
- e. Determination of cross-slope - per 324-5.8.
- f. Determination of pavement smoothness - per 324.5.9.
- g. Determination of the rejuvenator quantity.

324-5.2 Corrective Actions: Take prompt action to correct any errors, equipment malfunctions, process changes, or other assignable causes which have resulted or could result in the submission of materials, products, and completed construction which do not conform to the requirements of the specifications.

324-4 Construction.

324-4.1 General Requirements: Prior to commencing construction operations, repair all defective portions of the existing pavement as indicated in the plans. The minimum ambient temperature required for operations is 45°F. Clean the pavement such that it is reasonably free from loose materials, sand, dirt, caked clay and other deleterious substances. Remove and dispose of all reflective pavement markers. Remove thermoplastic striping prior to hot-in-place recycling operations.

324-4.2 Milling: Use the cold milling process per Section 327 to remove the upper layer(s) of asphalt above the reworked layer, if shown in the plans. Use cold milling, hot milling or hot scarifying to remove the existing reworked layer for recycling.

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- b. Depth determination (uncompacted mix) - once per 100 feet.
- c. Determination of pavement thickness (roadway cores) - per 324-5.7.
- d. Density determination (roadway cores) - one core per 1,000 feet.
- e. Determination of cross-slope - per 324-5.8.
- f. Determination of pavement smoothness - per 324.5.9.
- g. Determination of the rejuvenator quantity.

324-5.2 Corrective Actions: Take prompt action to correct any errors, equipment malfunctions, process changes, or other assignable causes which have resulted or could result in the submission of materials, products, and completed construction which do not conform to the requirements of the specifications.

324-5.3 Recovered Binder: Monitor the penetration or viscosity of the recovered asphalt binder during production. Obtain samples on a random basis at a minimum frequency of once per day. Recover the binder from the asphalt mixture in accordance with FM 5-524 and FM 3-D 5404. Maintain the penetration of the recovered asphalt material in the asphalt mixture (determined in

accordance with AASHTO T 49), within plus or minus 10 dmm of the target penetration value as indicated on the mix design and within the range of 40 – 80 dmm or maintain the viscosity of the recovered asphalt material in the asphalt mixture (determined in accordance with AASHTO T 202), within the range of 5,000 to 15,000 poises. If two or more consecutive tests exceed this tolerance, stop all recycling operations until the problem is adequately corrected.

324-5.4 Air Voids: Maintain an air void content of the asphalt mixture within the range of 2.0 to 6.0%. Air voids shall be based on specimens compacted in accordance with AASHTO T 312-08 and a maximum specific gravity as determined in accordance with FM 1-T 209. When the air void content of the asphalt mixture falls outside of this range, remove and replace or rework these areas and make all necessary adjustments to the blend of materials to modify the air void content to an acceptable level.

324-5.5 Asphalt Binder Content and Mix Gradation: Obtain samples randomly and test the samples in accordance with FM 5-563 and FM 1-T 030. Maintain an asphalt content within plus or minus 0.55% of the target asphalt content as indicated on the mix design. In the event the asphalt content deviates by more than 0.55% from the target, make all necessary corrections. If the test results for two consecutive samples both deviate by more than 0.55% from the target, stop all operations and make adjustments to assure that the asphalt content is within 0.55% of the mix design target. Maintain the percent passing the No. 200 sieve within plus or minus 2.5% of the target gradation as indicated on the mix design. In the event the percent passing the No. 200 sieve deviates by more than 2.5% from the target, make all necessary corrections. If the test results for two consecutive samples both deviate by more than 2.5% from the target, stop all operations and make adjustments to assure that the percent passing the No. 200 sieve is within 2.5% of the mix design target.

324-5.6 Density: The in-place density of the reworked asphalt layer will be evaluated by the use of 6-inch diameter roadway cores. The in-place density will be based on the daily maximum specific gravity (Gmm) of the as-produced mix. Obtain the roadway cores at random locations identified by the Engineer at the end of each day's production prior to opening the roadway to traffic, at a minimum frequency of one core per 1,000 feet or portion thereof for distances less than 1,000 feet. Assume responsibility for maintenance of traffic, coring, patching the core holes, and trimming the cores to the proper thickness prior to density testing.

Determine the density of the cores in accordance with FM 1-T 166, and calculate an average for each LOT, which for purposes of mixture process control, is defined as 5,000 feet. The average density of a LOT shall be a minimum of 92.0% of Gmm. Take corrective actions for those LOTs that have an average density less than 92.0% of Gmm. If two consecutive LOTs are less than 92.0% of Gmm, stop construction until appropriate adjustments are made to assure the minimum density requirement is met. Remove and replace or rework areas with an average density less than 90.0% of Gmm.

Once the average density of a LOT has been determined, do not provide additional compaction to raise the average.

324-5.7 Pavement Thickness: The thickness specified in the Plans shall be the compacted in-place thickness. The thickness shall be determined by the average measurement of roadway cores. Obtain cores at locations determined by the Engineer at a frequency of either one core per 1,000 feet or five cores per day, whichever is less. Thickness can also be determined based on cores cut for the evaluation of density as specified in 324-5.6. Maintain the average thickness of the reworked asphalt layer (based on roadway cores) within 1/4 inch of that specified in the Plans. If the average thickness is deficient by more than 1/4 inch but no more than 1/2 inch, take

appropriate corrective actions. If the average thickness is deficient by more than 1/2 inch, take additional cores to determine the area of deficient thickness. Correct any area deficient in thickness by more than 1/2 inch at no cost to the Department. If the average thickness is deficient for two consecutive days by more than 1/4 inch of that specified in the Plans, stop construction activities until adjustments are made to the operation that will allow placement at the specified depth. Continued operations when the thickness is deficient by more than 1/4 inch of the thickness specified in the Plans will not be allowed.

324-5.8 Cross Slope: Construct a pavement surface with cross slope meeting the requirements of 330-12.3.

324-5.9 Pavement Smoothness: Construct a smooth pavement meeting the requirements of 330-12.4.

324-6 Sampling and Testing for Acceptance by the Engineer.

The Department will randomly obtain and test samples of the reworked asphalt layer for acceptance in accordance with the test methods described in 324-5. Material meeting the criteria of Table 324-1 will be accepted at full pay. The frequency of sampling and testing will be one set of tests per lane mile or portion thereof.

Table 324-1 Acceptance Criteria for Department Tests

Characteristic	Acceptable Limits
Asphalt Binder Content (percent) (1)	Mix Design Target \pm 0.60
Passing No. 200 Sieve (percent) (1)	Mix Design Target \pm 3.0
Laboratory Compacted Air Voids (percent) (2)	2.0 to 6.0
In-place Density, minimum percent Gmm (3)	90.0
In-place Density, maximum percent Gmm (3)	96.0

Notes:

(1) Based on one test result.

(2) Based on the average value of two gyratory compacted specimens and one Gmm test.

(3) Based on the average value of five roadway cores and one Gmm test.

GEORGIA HOT IN-PLACE RECYCLING SPECIFICATION

Section 403—Hot In-Place Recycled Asphaltic Concrete

403.1 Description

This Section covers the hot in-place recycling of the existing surface in a continuous multi-step process which includes:

- Softening the existing surface with heat
- Hot milling to obtain the depth shown in the plan typical section or stated in the contract general notes
- Applying a tack coat
- Applying a rejuvenating agent
- Adding plant produced asphaltic concrete and virgin aggregate, if needed, prior to remixing
- Thoroughly remixing, leveling, and relaying the recycled mixture

403.1.01 Definitions

General Provisions 101 through 150.

403.1.02 Related References

A. Standard Specifications

Section 106
Section 109
Section 400
Section 402
Section 800
Section 824

B. Referenced Documents

AASHTO T-49
AASHTO T-209
AASHTO TP 4
AASHTO TP 5
ASTM D92
ASTM D2170
ASTM D2872
ASTM D4124
GDT 38
GDT 42
GDT 66
GDT 83
GDT 115

GDT 119
GDT 125
GDT 126
GSP 15

403.1.03 Submittals

Submit the proposed mix design for approval. As a minimum, the design shall include the following:

- The proportional blend of in-place materials and rejuvenating agent
- The proportional percentage of virgin aggregate and plant-produced hot mix asphalt, if required
- The sources of all materials to be used in the mixture
- The theoretical maximum specific gravity of the final mixture determined by AASHTO T-209
- The air void volume of the mixture after compacting for 50 gyrations with a gyratory compactor according to AASHTO TP 5

Use an approved, qualified laboratory to perform the mixture design analysis. Ensure the final design mixture has an air void volume within 3-5%.

Submit to the Office of Materials and Research (OMR) representative samples of each ingredient to be used in the final in-place mixture for design verification and additional testing as needed. The Department will perform testing for moisture and rutting susceptibility. Adjust mixture proportions as needed to ensure the final mixture meets the following requirements:

- Average rut depth not to exceed 0.3 in (7 mm) when tested using GDT 115.
- Minimum tensile splitting ratio of 80% and minimum individual stress results of 60 psi (415 kPa) when tested using GDT 66.

EXCEPTION: A tensile splitting ratio of no less than 70% is acceptable so long as all individual test values exceed 100 psi (690 kPa).

Allow the Department two weeks to verify the mix design after receiving the proposed mix design and material. Do not begin recycling operations until the Department has approved the design and accepted the mixture.

403.2 Materials The materials to be used and their specifications are listed below:

A. Aggregate

Add virgin aggregate, if required, which is from an approved source and which meets requirements of Section 800. Use the stone size and spread rate specified in the plans. Additional virgin aggregate from approved sources may be added based on the mixture design analysis at no additional cost to the Department.

B. Plant-Produced Hot Mix Asphaltic Concrete

Add the type and amount of plant-produced asphaltic concrete, if required, as specified in the plans. Additional asphaltic concrete may be added based on the mixture design analysis at no additional cost to the Department. Ensure the hot mix asphaltic concrete is produced according to Section 400 and Section 402.

C. Asphalt Cement Rejuvenating Agent

Obtain approval by the Office of Materials and Research for the source, amount, and type of rejuvenating agent to be used. The Department reserves the right to change, without a change in the contract unit price, the agent and amount being used in the mixture if it is determined by the Engineer that the rejuvenating agent is not performing satisfactorily.

D. Bituminous Tack Coat

Use a cationic asphalt emulsion CRS-2h, CSS-1h, or CQS-1h for the bituminous tack coat that meets Section 824. Apply the tack coat with a system equipped with positive stop/start capabilities that will prevent tack puddles and which will uniformly distribute the tack across the full width of the surface being recycled. Apply tack after the existing surface has been heated, milled, and removed from the roadway and prior to replacing the material onto the roadway.

E. Asphalt Modifier Provide asphalt modifier as specified in the Plans. It shall be added at a dosage rate that will yield at least 3% solid polymer by weight of the asphalt cement of the in-place material. Asphalt modifiers shall be approved by the Office of Materials and Research prior to use in the work. The Department reserves the right to change the type modifier and amount to be used, without a change in the contract unit price, if the Engineer determines that the asphalt modifier is not performing satisfactorily.

403.2.01 Delivery, Storage, and Handling**A. Aggregate Storage**

Store or stockpile mineral aggregates in a manner that will prevent segregation, mixing of the various sizes, and contamination with foreign materials.

B. Storage of Bituminous Material

Always keep clean all equipment used to store and handle bituminous material and operate it in such a manner to prevent contamination with foreign matter.

403.3 Construction Requirements**403.3.01 Personnel**

General Provisions 101 through 150.

403.3.02 Equipment

The Engineer shall approve all equipment, tools, and machines used to perform this work. Do not attempt work with malfunctioning equipment. The Engineer may stop the work if equipment and tools are not sufficient to place the materials satisfactorily.

A. Heating and Milling Units

Ensure the heating unit meets the following requirements:

- Capable of heating the asphaltic concrete pavement to a temperature high enough to remove excess moisture and allow hot milling of the material to the designated plan depth without breaking aggregate particles
- Controls the heating process to prevent charring the existing surface, avoid producing undesirable pollutants, and prevent differential softening of the pavement
- Confine the heat application under a shielded, or enclosed, hood

Protect adjacent landscape from heat damage. Rebuild, repair, restore, and make good all injuries or damages to adjacent landscape, at the Contractor's expense. Equip the unit which contains milling heads with longitudinal grade controls as described in Subsection 403.3.02.C which will consistently control the depth of the milling operation. Milling heads shall remove the heated existing pavement to the depth specified in the Plans for the full transverse width even if additional virgin aggregate or asphaltic concrete mixture is added at no cost to the Department.

Use a portable milling or scraping unit to completely remove heated material from around utility structures to the full plan depth just prior to placement of the recycled material. Do not attempt to remove heated material from utility structures with hand tools only and do not damage the structures. Repair any damage to structures at no additional cost to the Department.

B. Blending Unit

Provide a blending unit which meets the following requirements:

- Capable of blending the removed material and rejuvenating agent (as well as virgin aggregate, asphalt modifier, and plant-produced hot mix asphaltic concrete, if required) into a homogeneous mixture
- Synchronizes application of all materials based on the volume of material being recycled to provide a proportional application at the predetermined application rate

Add the rejuvenator after milling has taken place and before or during the blending process with a positive start/stop mechanism that is automatically controlled by the volume of recycled material to be rejuvenated. Do not add rejuvenator based on linear distance travelled.

Add asphalt modifier, if required, at locations specified in the Plans or directed by the Engineer. Add modifiers during the blending process through a distribution system that will uniformly control the rate of application based on the volume of material being recycled and which contains a measuring system to verify the dosage rate.

C. Screed

Ensure the screed meets the following requirements:

- Capable of collecting and distributing the recycled mixture over variable widths for the entire width being processed
- Capable of controlling transverse cross-slope as directed by the Engineer
- Provides a uniform cross-section without streaks or blemishes
- Controls longitudinal grade electronically in conjunction with a mobile reference or by a non-contacting laser or sonar type ski with at least four referencing stations mounted at a minimum length of 24 feet (7.2 m)

D. Auxilliary Equipment

Provide suitable surface cleaning equipment, hand tools, rollers, and other support equipment necessary to perform the work. Ensure all other equipment meets requirements of Section 400.

403.3.03 Preparation General Provisions 101 through 150.

403.3.04 Fabrication General Provisions 101 through 150.

403.3.05 Construction

A. Surface Preparation

Thoroughly clean the surface to be recycled of all dirt, vegetation, and other objectionable materials immediately prior to the affected area being recycled. Remove all metal raised pavement markers and thermoplastic paint markings prior to recycling.

B. Heat, Remove, and Blend Materials

Evenly heat the pavement at full lane width plus a minimum 3 in (75 mm) overlap onto adjacent pavement materials. Control the heating to ensure uniform penetration without differential softening of the surface, and so that the heated material has a temperature in the range of $240 \pm 20\text{F}$ ($115 \pm 11\text{C}$) measured immediately behind the heating unit. If virgin aggregate is added, distribute the aggregate across the entire width being recycled prior to the last heat application.

Hot mill and rework the pavement to the width and depth shown in the plan typical section. Control the width of each pass to provide proper placement of longitudinal joints. Control the depth of loosened pavement to within 1/4 in (6 mm) of the depth specified. Ensure the milled

material is heated sufficiently so that it is free of lumps. Milled particles shall not be greater than 1-1/2 in (40 mm) in size.

Blend the removed material with a rejuvenating agent (and virgin aggregate, asphalt modifier, or plant-produced hot mix asphaltic concrete, if needed) to produce a homogeneous mixture. Control the rate of application of the rejuvenator to ensure compliance with the mix design and Dynamic Shear Rheometer (DSR) values specified in Subsection 403.3.06.A. Apply other materials as specified in the contract or as determined by the mix design analysis.

C. Tack Coat

Apply tack coat uniformly over the milled area prior to placement of the blended materials. Control the application rate within 0.04 – 0.06 gal/yd² (0.18 – 0.27 L/m²).

D. Application

Control placement of the mixture to produce a surface true to line, grade, and cross-slope with a uniform surface texture free of segregation, lumps, or other unacceptable streaks or blemishes as determined by the Engineer. Ensure the mixture meets the acceptance requirements for mixture quality, compaction, smoothness, and thickness as specified in Subsection 403.3.06.

E. Overlay

Overlay the recycled mixture, if required by the contract, by producing and placing a mixture that meets requirements of Section 400 and Section 402. Smoothness requirements for the hot in-place recycled mixture do not apply if the mixture is overlaid.

403.3.06 Quality Acceptance

A. Mixture

Base acceptance of the materials used in the work on Section 106 and Section 400 except that pay factors for gradation and asphalt content will not apply. Take a minimum of one sample of mixture for each day of operation to determine quality acceptance of the mixture.

Take samples directly behind the paver according to GSP 15 at the location determined by the engineer. Perform extraction and gradation testing according to GDT 83 and GDT 38 or other suitable method approved by the Office of Materials and Research. Determine the laboratory density of the mixture at 50 gyrations with a gyratory compactor using AASHTO TP 4.

Recover the extracted asphalt cement using GDT 119 and test for dynamic shear according to AASHTO TP 5, Method for Determining the Rheological Properties of Asphalt Binder Using Dynamic Shear Rheometer (DSR). Adjust the amount of rejuvenator as necessary to maintain DSR results within a range of 800-2000 poises (80-200 Pa-s) when tested at 140F (60C). Do

not continue the work until corrective adjustments are made if two consecutive samples exceed the range for DSR values.

Submit test results electronically to the Engineer and Office of Materials and Research within 24 hours after samples are taken.

B. Compaction

Compact the recycled mixture immediately after placement so that the maximum Pavement Mean Air Voids is 7.8 percent or less. Determine the mixture compaction using either GDT 39 or GDT 59. The compaction is accepted in lots defined in Subsection 400.3.06.A “Acceptance Plans for Gradation and Asphalt Cement Content” and is within the same lot boundaries as the mixture acceptance. Meet the compaction requirements of Subsection 400.3.06.B. and Subsection 400.5.01.C. The Department will perform all compaction testing.

C. Smoothness

The Department will perform acceptance testing for surface course smoothness tolerance using the Laser Road Profiler according to GDT 126. Smoothness testing will be performed on the mainline traveled way and on ramps more than one-half mile (kilometer) in length.

Clean the roadway of any debris and obstructions and provide traffic control to conduct the testing when requested by the engineer.

Ensure the pavement does not exceed a target smoothness index of 900. Do not continue the work until corrective adjustments have been made if the target value is exceeded. Perform corrective work at no expense to the Department by repeating the hot in-place recycling process, according to this Section, if the smoothness index exceeds 1025.

Maintain a 10 ft. (3 m) straightedge in the vicinity of the paving operation at all times to use in measuring minor surface irregularities and provide the labor for its use. Correct all irregularities in excess of 1/8 in (3 mm) in 10 ft. (3 m). Stop the operation until corrective measures are taken when irregularities such as rippling, tearing, or pulling indicate a continuing problem in equipment, mixture, or operating techniques.

D. Mill Depth

Mill heated material to the thickness specified in the plan typical section or contract general notes. The Department will take cores at a minimum frequency of one core per 1000 ft (300 m) per two lanes of roadway or five cores per day, whichever is less, to verify mill depth.

The Department will determine the average mill depth based on roadway core measurements according to GDT 42. Mill depth will be determined based on total rejuvenated thickness less any thickness contributed by added virgin materials.

To receive full payment for mill depth, ensure the average milled depth is no less than 1/4 in (6 mm) of that specified in the plan typical section or contract general notes. Apply a pay reduction of 25% to the total square yards (meters) applied that day if the average depth is less than that specified, by more than 1/4 in (6 mm) but no more than 1/2 in (13 mm) of that specified.

Take additional cores to determine the area of deficient depth if the average depth is less than that specified, by more than 1/2 in (13 mm). Correct any areas deficient in depth by more than 1/2 in (13 mm) by repeating the hot in-place recycling process at no expense to the Department. Stop the work until corrective measures are made if the average mill depth for two consecutive days is less than 1/4 in (6 mm) of that specified.

403.3.07 Contractor Warranty and Maintenance

General Provisions 101 through 150.

403.4 Measurement

Hot in-place recycled asphaltic concrete mixture is measured by the square yard (meter) of the surface area completed and to the depth specified. In computing square yards (meters), the lengths and widths used shall be as specified in Section 109, Measurement and Payment.

Rejuvenating agent, virgin aggregate, and plant-produced asphaltic concrete shall be added as individual components of the recycled mixture as required in the mix design analysis. Include this cost in the unit bid price per square yard (meter). Bituminous materials for tack coat applied and accepted will be measured as outlined in Section 109.

403.4.01 Limits

General Provisions 101 through 150.

403.5 Payment

Hot in-place recycled asphaltic concrete is paid for at the contract unit price per square yard (meter). Payment is full compensation for furnishing all materials, all equipment, Work, and labor. Payment also includes removal of raised pavement markers and thermoplastic striping, if applicable, heating and hot-milling, adding rejuvenator, performing the mix design, performing project sampling and testing, and other incidentals necessary to complete the work. Aggregate and hot mix asphaltic concrete which may be added to meet requirements of the mix design analysis shall be included in the contract unit price.

Bituminous tack coat is paid for per gallon (liter) under separate payment. Hot mix asphaltic concrete specified for overlaying, if any, will be paid for under separate payment. Aggregate specified in the contract, if any, (excluding that required based on the mix design analysis) will be paid for under separate payment. Payment will be made under:

403.5.01 Adjustments

General Provisions 101 through 150.

Item No. 403	Hot in-place recycled asphaltic concrete	Per square yard (meter)
Item No. 403	Hot in-place recycled asphaltic concrete including polymer-modifier	Per square yard (meter)

NORTH CAROLINA HOT IN-PLACE RECYCLING SPECIFICATION

SECTION 663
HOT IN-PLACE RECYCLED ASPHALT CONCRETE

663-1 DESCRIPTION

This work shall consist of hot in-place recycling of the existing asphalt concrete surface by heating and softening the existing asphalt pavement with indirect heat, loosening the heated pavement by hot milling to the depth specified in the plans, adding a plant produced hot mix asphalt admixture, if required, applying a rejuvenating agent, thoroughly remixing the material in a pugmill, leveling, relaying and compaction of the hot-in-place recycled (HIR) asphalt mixture. Use a continuous, single train, single pass, multi-step process to accomplish this work.

Hot In-Place Recycled Asphalt Concrete production and placement, including all materials and equipment shall be in accordance with applicable provisions of Division 6 except as specifically noted or modified herein.

Provide and conduct the quality control and required testing for acceptance of the HIR mixture in accordance with Quality Management System For Asphalt Pavements (Hot In-Place Recycled Asphalt), included herein.

663-2 MATERIALS**(A) Hot Mix Asphalt Admixture**

Determine the type and amount of plant produced hot mix asphalt (HMA) admixture to be added to the recycled mixture, subject to the approval of the Engineer. The HMA admixture shall be a plant mixture of asphalt binder and aggregate(s) meeting the applicable requirements of Division 10 as shown below. The aggregate in the admixture may be a single standard size aggregate or a combination of aggregate sizes as needed. Provide enough binder content for the admixture such that the aggregate particles are fully coated. Provide a gradation and binder content for the admixture such that when blended with the other mix components, the hot in-place recycled mix properties will meet the mix design criteria for the applicable mix type specified in the plans, unless otherwise approved by the Engineer. Produce the HMA admixture in accordance with applicable requirements of Division 6.

Coarse Aggregate	Article 1012-1
Fine Aggregate	Article 1012-1
Stone Screenings	Article 1012-1
Asphalt Binder	Article 1020-2
Anti-strip Additive	Article 1020-8

(B) Asphalt Rejuvenating Agent

Use an asphalt rejuvenating agent meeting the following requirements

	Minimum	Maximum
Viscosity, 77F, SFS, ASTM D-244	20	125
Sieve, %, ASTM D-244	-----	0.10
Storage Stability, 24 hr, %, ASTM D-244	-----	1
Residue from distillation, % (1)	60	-----
Oil Distillate, Volume %	-----	5
Tests on Residue and Rolling Thin-film Oven Tests: (2)		
Penetration @ 77F, 5 sec.	300	-----
Torsional Recovery 39.7F, %	20	-----

Notes: (1) ASTM D244 except that the maximum temperature shall be 350F held for 20 minutes.

(2) The residue from distillation shall be subject to the standard rolling thin film oven test.

663-3 COMPOSITION OF MIXTURE (Mix Design /Job Mix Formula)

(A) Mix Design-General

Prepare and submit a proposed HIR mix design and job mix formula to the Engineer at least 14 days prior to beginning work in accordance with all applicable requirements of Article 610-3 except as modified herein. In addition, submit a proposed mix design for the admixture if an admixture is required.

Sample the existing pavement by coring or other methods approved by the Engineer to determine representative characteristics and properties of the existing pavement for use in mix design preparation. Take these samples at a minimum of one sample every 2000 linear feet of each lane. Provide samples for quality assurance testing when requested by the Engineer. Take these all samples in the presence of the Engineer and at locations approved by the Engineer.

Perform and document a mix design in accordance with the Department's most current accepted policies and procedures for the design of asphalt mixes. The Department's Asphalt Design Engineer at the Materials and Tests Unit may be contacted for copies of these procedures. Establish the proposed HIR mix design such that the hot in-place recycled mix properties are within the design criteria for the type mix specified, unless otherwise approved by the Engineer. Submit the mix designs on forms and in the format approved by the Department. Once the proposed mix designs are approved, the Engineer will provide approved Job Mix Formulas.

In addition to applicable mix design data required in Sub-article 610-3 (A), the data shall include but not be limited to the proposed percent admixture, if needed, admixture components, gradation, binder grade, binder content, percent anti-strip additive in admixture, percent existing pavement (RAP), gradation and binder content of existing pavement, percent rejuvenating agent, penetration of recovered binder from total mix, and all mix design properties and calculations.

(B) Mix Design Criteria

The finished asphalt pavement shall be a uniform mixture composed of the existing in-place asphalt pavement, asphalt rejuvenating agent, and new hot mix asphalt admixture, if required. The hot in-place recycled asphalt mix shall meet applicable requirements of Section 610-3 (excluding maximum percentage of allowable RAP) for the mix type specified, except as modified herein.

The proposed HIR mix design shall be established such that the hot in-place recycled mix properties will meet applicable gradation and mix design requirements of Table 663-1 and Table 663- 2 for the mix type specified, except as modified herein, unless otherwise approved by the Engineer

Add an asphalt rejuvenating agent at a rate that yields a completed mixture with a minimum/maximum penetration value as specified in Table 663-2 below, unless otherwise approved by the Engineer.

TABLE 663-1 AGGREGATE GRADATION DESIGN CRITERIA

Standard Sieves (mm)	Percent Passing Criteria (Control Points) Mix Type (Nominal Maximum Aggregate Size)					
	9.5 mm		12.5 mm		19.0 mm	
	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>	<u>Min.</u>	<u>Max.</u>
50.0						
37.5						
25.0					100.0	
19.0			100.0		90.0	100.0
12.5	100.0		90.0	100.0		90.0
9.5	90.0	100.0		90.0		
4.75		90.0				
2.36**	32.0**	67.0**	28.0	58.0	23.0	49.0
1.18						
0.600						
0.300						
0.150						
0.075	4.0	8.0	4.0	8.0	3.0	8.0

**NOTE: For Type SF 9.5A the percentage passing the 2.36 mm sieve is 60% minimum and a maximum of 70%.

Aggregate Nominal Maximum Size is defined as one standard sieve size larger than the first sieve to retain more than 10 percent aggregate. Maximum Size is defined as one standard sieve size larger than the nominal maximum size.

Table 663-2 MIX DESIGN CRITERIA

Mix Type (a)	Design ESALs (millions)	Target Binder PG Grade	Compaction Levels			Volumetric Properties (b) (AASHTO PP 28)			
			No. Gyration @ Nini	Ndes	Nmax	VMA % Min.	VTM %	VFA Min.- Max.	%Gmm @ Nini
SF-9.5A	< 0.3	64 - 22	6	50	75	16.0	3.0 - 5.0	70 - 80	≤ 91.5
S-9.5A	< 0.3	64 - 22	6	50	75	15.0	3.0 - 5.0	70 - 80	≤ 91.5
S-9.5B	0.3 - 3	64 - 22	7	75	115	15.0	3.0 - 5.0	65 - 80	≤ 90.5
S-9.5C	3 - 30	70 - 22	8	100	160	15.0	3.0 - 5.0	65 - 76	≤ 89.0
S-12.5B	< 3	64 - 22	7	75	115	14.0	3.0 - 5.0	65 - 78	≤ 90.5
S-12.5C	3 - 30	70 - 22	8	100	160	14.0	3.0 - 5.0	65 - 75	≤ 89.0
I-19.0B	< 3	64 - 22	7	75	115	13.0	3.0 - 5.0	65 - 78	≤ 90.5
I-19.0C	3 - 30	64 - 22	8	100	160	13.0	3.0 - 5.0	65 - 75	≤ 89.0

	Design Parameter	Design Criteria
All Mix	1. %Gmm @ Nmax	≤ 98.0% (c)
	2. Penetration(AASHTO T 49) from Abson Recovery (AASHTO T 170)	40 Min. 90 Max

Notes: (a) Based on 20 year design traffic.

(b) Volumetric Properties based on specimens compacted to Ndes as modified by the Department.

(c) Based on specimens compacted to Nmax at selected optimum asphalt content.

(d) Mix Design Criteria may be modified, subject to approval by the Engineer.

(C) Job Mix Formula

Once the proposed mix design is approved, the Engineer will provide a Job Mix Formula for the hot in-place recycled asphalt mix. The job mix formula will be established within the design criteria in Tables 663-1 and 663-2, unless otherwise approved by the Engineer.

Once the HIR mix design is approved, the Engineer will provide a Job Mix Formula for the admixture if admixture is required. The completed admixture shall be produced in accordance with the Job Mix Formula requirements for gradation and binder content as prescribed in Quality Management System for Asphalt Pavements (Hot In-Place Recycled Asphalt Concrete – Superpave Version) as shown in the contract.

Samples of the completed recycled mixture may be taken by the Department on a random basis to determine if the PG grading on the recovered asphalt binder is in accordance with AASHTO M 320 for the grade specified. If the grading is determined to be a value other than required for the specified mix type, the Engineer

may require the Contractor to adjust the grade and/or percentage of additional asphalt binder, asphalt rejuvenator, and/or the blend of reclaimed material and admixture to bring the PG grade to the specified value for the required mix type, in accordance with Table 663-2.

663-4 EQUIPMENT

(A) General

Equipment used to recycle the existing asphalt surface shall be designed and built for this specific purpose. The equipment shall be capable of a single pass, multi-step operation that includes; multi-step heating, milling, introducing rejuvenating agent, introducing hot mix asphalt admixture, if required, mixing the new material with the reclaimed material in a separate on-board chamber, redistributing the recycled material, leveling, and compacting the mixture.

(B) Heating Unit

Preheating mechanism(s) consisting of clusters of heaters capable of uniformly heating the asphalt pavement to a temperature high enough to remove excess moisture, to allow milling of the existing pavement material to the designated plan depth without excessive fracturing of aggregate particles, without charring the existing asphalt and without producing undesirable pollutants. The heating mechanism shall be so equipped that the heat application shall be completely under an enclosed or shielded hood. The unit shall be adjustable in width. The Contractor shall protect adjacent landscape from heat damage and shall be responsible for any damage that may occur.

(C) Milling/Blending Unit

A self propelled processing unit containing the following:

- (1) A recycling machine equipped with additional heaters conforming to the same requirements as the preheaters.
- (2) A unit capable of uniformly loosening the existing asphalt pavement to the depth specified. Care must be taken to ensure that milling or pavement reclaiming does not degrade the aggregates but only loosens the heated existing pavement.
- (3) A controlled system for adding and uniformly blending a rejuvenating agent at a predetermined rate with the reclaimed mix during the remixing and leveling operation. The metering equipment shall be capable of measuring in gallons. The application rate in gallons, for the added material, shall be synchronized with the machine ground speed to provide a uniform application. The actual rate used may be adjusted as determined
- (4) A blending unit consisting of a twin shafted pugmill capable of uniformly adding new hot mix asphalt admixture, if required, at a rate established by the

mix design. The unit shall be capable of thoroughly mixing the loosened asphalt pavement, asphalt rejuvenating agent, and new hot mix asphalt admixture if required, at the pugmill to produce a uniform mixture.

- (5) A unit capable of auguring the heated and loosened material into a windrow at the center of the machine prior to entry into the blending unit.
- (6) A paving machine meeting the requirements of Article 610-8 of the Standard Specifications, except as modified herein, shall be utilized to redistribute the remixed material over the width being processed and finished, so as to produce a uniform cross section and surface. The paving machine must be capable of screeding the full width of the remixed material. Automatic screed controls meeting the requirements of this Article shall be provided and used unless otherwise approved by the Engineer.
- (7) The recycling train shall be capable of maintaining an average production rate of a minimum of 1 lane mile per day.
- (8) The reheating and remixing units shall meet all state and local air quality emission standards for mobile sources.

(D) Compaction Equipment

Rollers meeting the requirements of Section 610-9 of the Standard Specifications and capable of achieving the specified density and surface requirements shall be utilized.

663-5 CONSTRUCTION REQUIREMENTS

Hot In-place recycled mixtures shall not be produced or placed during rainy weather or when the air temperature measured in the shade away from artificial heat at the location of the paving operations is less than 50oF. Do not place surface course material that is to be the final layer of pavement between December 15 and March 16 of the next year.

Prior to heating and remixing operations, the pavement shall be cleaned of all loose material. Power brooms shall be used and supplemented when necessary by hand brooming or other cleaning operations, as required, to bring the surface to a clean, suitable condition free of deleterious material.

The pavement surface shall be evenly heated, loosened, and remixed to the lines, grades and depths shown on the plans. Heating shall be controlled to ensure uniform heat penetration without overheating, cooking, or sooting of the asphalt pavement. The milled material shall be picked up, mixed with an asphalt rejuvenator and asphalt admixture, if needed, in a pugmill and then distributed and leveled by a conventional paving machine. The temperature of the milled material shall not be more than 325oF when measured immediately behind the milling unit. The temperature of the remixed material shall not be less than 235oF directly behind the screed.

The heating operation shall extend at least 4 inches beyond the width of remixing on

both sides. When a pass is made adjacent to a previously placed mat, the longitudinal joint shall extend at least 2” into the previously placed mat.

The layer thickness of the HIR specified in the Plans or Contract Proposal shall be the compacted in-place thickness of the rejuvenated recycled mixture layer including any admixture. The depth of milling of the existing surface shall be such that the depth as specified on the plans is within $\pm 1/4$ inch, unless otherwise approved by the Engineer.

The asphalt rejuvenator shall be applied uniformly to the mixed material prior to remixing in the pugmill. The rate of application of rejuvenator will be as specified on the Job Mix Formula approved by the Engineer based upon the Contractor’s proposed mix design.

The remixed asphalt pavement shall be compacted immediately after it has been spread and leveled, while it is still in a workable condition.

Density control may be by either core samples or nuclear density control in accordance with the Department's most current procedures. Density for HIR mixes shall be a minimum of 92.0 percent of Maximum Specific Gravity (Gmm), except for SF9.5A that will be 90.0 percent of the Maximum Specific Gravity (Gmm). The Maximum Specific Gravity (AASHTO T 209) will be determined by procedures specified in the Department’s most current edition of the HMA/QMS Manual.

The compacted surface of the completed and accepted pavement structure shall meet the requirements of Article 610-12 of the Standard Specifications.

The Contractor shall take precautions needed to protect the adjacent landscape from heat damage. Damaged landscape shall be repaired or replaced at no cost to the Department.

663-6 MEASUREMENT AND PAYMENT

Hot In-Place Recycled Asphalt Concrete, Type___ will be measured and paid for by the square yard in the completed and accepted work.

Asphalt Rejuvenating Agent to be paid for will be measured by the metered quantity in gallons used in all completed and accepted work and will be paid for at the contract price per gallon.

Hot Mix Asphalt Admixture will be measured and paid for, when required, will be measured by being weighed in trucks on a certified weighing device and documented on load tickets and will be paid for at the contract unit price per ton.

Asphalt binder to be paid for will be measured and paid for in accordance with Article 620.

The above prices and payments will be full compensation for all work covered by this

section including but not limited to furnishing all materials, producing, weighing, transporting, placing, and compacting the recycled pavement; maintaining the finished course until final acceptance of the project, performing quality control as specified in the contract and making any repairs or corrections to the surface of the pavement that may become necessary.

Payment will be made under:

Pay Item	Pay Unit
Hot In-Place Recycled Asphalt Concrete, Type _____	Square Yard
Emulsified Asphalt Rejuvenating Agent	Gallon
Hot Mix Asphalt Admixture	Ton

TEXAS HOT IN-PLACE RECYCLING SPECIFICATION

2004 Specifications

SPECIAL SPECIFICATION 3178

Hot In-Place Recycling of Asphalt Concrete Surfaces (HIR)

- 1. Description.** Use the hot in-place process to recycle the existing pavement in one of the following sub-categories described below.

Recycling. Recycling is the process in which the existing asphalt pavement is heated, softened and then milled. A recycling agent is added and the material is thoroughly mixed and placed with a standard paving screed.

Remixing. Remixing is similar to recycling with the addition of virgin aggregate or new hot mix asphalt added to the recycled material. The materials are then thoroughly mixed and placed with a standard paving screed.

Repaving. Repaving combines either recycling or remixing with an overlay of new hot-mix asphalt placed immediately after the recycled mixture. The new hot mix asphalt layer is placed directly on the recycled layer, and both are compacted simultaneously.

The Department will provide in the plans all typical sections and any grade change requirements; the depth and width of recycling required; core information from the existing roadway to include pavement layers, lift thicknesses; the AC content and penetration value of the existing asphalt to be recycled plus any other data collected from the pavement evaluation.

- 2. Materials.**

A. Recycling Agent. Furnish a recycling agent in accordance with Section 4.A, "Mixture Design," and meeting the requirements of Section 300.2.F, "Recycling Agent."

B. Hot Mix Asphalt. If the process requires additional hot-mix asphalt, furnish new hot-mix asphalt that meet the requirements of Section 4.A. Use materials meeting the requirements of Article 340.2, "Materials," to produce the new hot-mix asphalt.

C. Aggregate. If the process requires additional aggregate, furnish aggregates to meet the requirements shown in Section 4.A, "Mixture Design." Use aggregates meeting the requirements of Article 340.2, "Materials."

- 3. Equipment.**

A. Processing Equipment. Provide equipment that is capable of a continuous single pass, multi-step operation, including heating; milling; introducing recycling agent, virgin materials, and/or hot mix asphalt (if determined necessary;) mixing the reclaimed material; redistributing the recycled material; placing the mix and leveling it with an asphalt paver or paving screed; and compacting the mixture, that meets the following requirements.

1. **Pavement Pre-Heaters.** Supply pavement pre-heaters capable of uniformly heating the existing pavement to a temperature high enough to remove excess moisture and allow dislodging of the material to the specified depth, while minimizing the fracturing of aggregate particles. Equip heaters with an enclosed or shielded hood to prevent damage to adjacent property or vegetation. Ensure that the heaters overlap the completed adjacent lane by a minimum of 6 in. to create a hot bond at the longitudinal joint.
2. **Pavement Milling Heads.** Provide milling heads for pavement recycling capable of uniformly loosening the entire pavement lane width to the depth specified in the plans. Accomplish the recycling by using milling heads that have a grade control system for each head. Ensure that the tooth spacing of the milling heads is sufficient to allow material to pass without excessive retention. Utilize equipment that is capable of raising and lowering the milling heads in order to recycle the material around manholes and other obstacles.

Equip the milling heads such that they are capable of gathering the heated and loosened asphalt concrete pavement. Operate the milling heads in such a manner to minimize aggregate degradation. Utilize milling heads that are capable of creating a windrow of the milled material ahead of the mixing chamber or subsequent milling units.

3. **Recycling Agent Application System.** Provide a system for adding and uniformly applying a recycling agent at the specified rate with the hot, loosened material. Control the system to within 5.0% of the target application rate. Equip the recycling agent system with positive on/off capabilities to prevent any dripping. Add the recycling agent during or after milling has taken place to provide uniform application of the recycling agent and adequate mixing with the recycled material during the mixing cycle.
4. **Mixing Unit.** Provide equipment with an on-board mixing chamber that is capable of thoroughly mixing the heated, reworked material with new materials. Enclose and configure the mixing chamber such that no milled material escapes or bypasses the mixer chamber. Ensure that the rotation of the mixer apparatus does not cause segregation during the mixing process.
5. **Paving Unit.** Furnish a paver or paver screed meeting the requirements Section 320.2.C.1, "Equipment."

- B. Rollers.** Provide rollers meeting the requirements of Article 210.2, “Equipment.”
- C. Broom.** Furnish rotary self-propelled power brooms. The broom should have positive control on the downward pressure applied to the surface.
- D. Mobile Testing Laboratory.** Unless otherwise shown on the plans, furnish a mobile testing laboratory meeting the requirements of Tex-237-F and a Level 1A certified laboratory technician qualified under the Department’s approved program. If fresh hot mix asphalt is added, perform the tests necessary to control plant production.
- 4. Construction.** Rehabilitate existing asphalt concrete pavement to meet the typical sections shown on the plans and the lines and grades established by the Engineer. The existing pavement should be heated and milled to the required depth of treatment as shown on the plans.
- A. Mixture Design.** Provide a mix design and job mix formula that meets the criteria of Table 1. Specimens will be compacted using the Superpave Gyratory Compactor in accordance with Tex-241-F at 50 gyrations. The target number of gyrations may be adjusted if allowed by the Engineer. Submit the completed mix design to the Engineer for approval prior to the start of the project. Perform additional mix designs based on road variability, as directed by the Engineer.
- 1. Sampling.** Obtain cores at intervals throughout the project to determine the existing condition of the roadway and account for variability within the project limits. Obtain an adequate quantity of material to perform the mixture design. Evaluate cores and note any evidence of material (rubber seal, fabric underseal, etc.) that could be detrimental to the process. A minimum of 2 in. of the existing pavement structure must remain in place following milling. Note any base or uncoated material that falls within the layer to be recycled. Notify the Engineer of any of these conditions before proceeding with the mix design.
 - 2. Job-Mix Formula Approval.** The job-mix formula (JMF) is the combined aggregate gradation and target asphalt recycling agent percentage established from the laboratory mixture design used for hot in-place production.
 - 3. Hot Mix Asphalt.** If the process requires new hot-mix asphalt, use materials meeting the requirements of Section 340.4.A, “Mixture Design,” to produce the new hot-mix asphalt. Document in the JMF the percentage of new hot-mix used in the laboratory mix design submitted to the Engineer.
 - 4. Aggregates.** If necessary, use aggregates meeting the requirements in Table 1 of Article 340.2, “Materials.”
 - 5. Other Additives.** If necessary, use additives to meet the requirements in Table 1. In the case that an additive is used, describe the type and allowable usage percentage in the submitted design recommendation.

Table 1
Laboratory Mix Design Requirements

Mixture Property	Test Method	Min	Max
Target laboratory molded density, %	Tex-207-F	96.0	
Theoretical Maximum Spec. (Rice) Gravity ¹	Tex-227-F	NA	
Tensile strength, lbs./in. ²	Tex-226-F	75	
Hamburg Wheel-tracking Test , 50°C, 10,000 cycles, mm	Tex-242-F		12.5
Overlay Test	Tex-248-F	Report Only	
Boil Test ²	Tex-530-C	-	
Combined Asphalt Property	Test Method	Min	Max
Penetration, 77°F, 100 g, 5 sec.	T49	40	80

1. Used to determine lab molded density.
2. Used to establish baseline for comparison to production results.

B. Pavement Heating. Heat the existing pavement without charring the existing asphalt and without producing undesirable pollutants. The temperature of the material immediately behind the heater should maintain a minimum of 200°F. Uniformly heat the pavement surface across its full lane width such that cold milling of the pavement surface does not occur.

C. Pavement Milling. Mill the existing pavement to the required depth and width as indicated on the plans. Do not disturb the underlying material in the existing roadway when recycling. Remove grass and other vegetation from the edge of the existing pavement to prevent contamination of the recycled bituminous material during this operation.

Utilize the milling heads to remove a minimum of 3 in. laterally of the completed adjacent pass and make a square vertical cut in the heated material such that a hot bonded longitudinal joint is achieved. Ensure that all material across the full lane-width is processed between consecutive lane passes to assure that any wedges (slivers) of unprocessed materials are not left untouched by the milling heads and covered by the recycled material, unless otherwise approved by the Engineer.

Ensure that the temperature of the milled surface directly behind the milling heads is greater than 160°F so that cold milling does not occur. All loosened asphalt material must be cleaned away by the milling heads, and a milling tooth pattern must be clearly visible after milling.

Remove all material around manholes and utility structures prior to paving the recycled mixture to allow for the plan depth of the pavement around these structures.

Cold mill and sweep clean any areas that cannot be heated and milled by the recycling equipment. Properly tack and pave these areas of cold milling in advance of the recycling process.

- D. Addition of Recycling Agent.** Incorporate the asphalt recycling agent into the hot recycled bituminous material at the rate determined by the approved mix design(s).

Sampling and testing during mixture production may result in varying quantities of recycling agent at different portions of the project in order to meet the requirements in Table 1. Change the recycling agent content only with approval of the Engineer.

- E. Placement of Recycled Material.** Spread the material using a paver and screed attached to the mixing/milling unit or a traditional paver in a separate and continuous operation meeting the requirements of Section 320.2.C.1, "Equipment." Spread the recycled material to the lines and grades established by the Engineer. Ensure the temperature of the recycled material behind paver is greater than 200°F.

- F. Compaction.** Compact the recycled mix using rollers meeting the requirements of Section 3.B, "Rollers." Establish rolling patterns to achieve the target air voids in accordance with Tex-207-F. Only operate rollers in vibratory mode when doing so does not damage the pavement. Compact the recycled mix to in-place air voids between 4% and 9%, unless otherwise shown on the plans. Follow the selected rolling pattern unless changes occur in the recycled mix or placement conditions, at which time establish a new rolling pattern. Adjust or cease compaction when cracking or displacement occurs. Ensure that pavement is fully compacted before allowing rollers to park on the pavement.

- G. Traffic.** After the completion of compaction of the recycled material, permit no traffic, including that of the contractor, on the completed recycled material until the material has cooled to 160°F or less. After opening to traffic, maintain the surface of the recycled pavement in a condition suitable for the safe movement of traffic. Remove all loose particles that may develop on the pavement surface by power brooming.

- H. Irregularities.** Immediately take corrective action if surface irregularities, including but not limited to segregation, rutting, raveling, flushing, fat spots, mat slippage, color, texture, roller marks, tears, gouges, streaks, or uncoated aggregate particles, are detected. The Engineer may allow placement to continue for at most 1 day of production while taking appropriate action. If the problem still exists after that day, suspend paving until the problem is corrected to the satisfaction of the Engineer.

At the expense of the Contractor and to the satisfaction of the Engineer, repair any areas with surface irregularities as identified above prior to the placement of any hot mix asphalt surface course or other applicable surface treatment.

I. Curing. A surface treatment may be allowed as the final riding surface when shown on the plans. If hot-mix asphalt concrete or another applicable surface treatment is placed as a surface course, allow the hot in-place recycled bituminous material to cure for a minimum of 7 days, or as directed by the Engineer.

J. Weather Limitations. Unless otherwise approved, perform hot in-place recycling operations when the existing pavement surface temperature is 60°F or higher and when weather conditions and moisture conditions of the roadway surface are suitable, in the opinion of the Engineer.

5. Quality Control. Perform the quality control tests listed in Table 2. If operational tolerances in Table 2 are exceeded, adjust processes or cease production when directed by the Engineer. The Engineer may perform independent tests to confirm contractor compliance and may require testing differences or failing results to be resolved before resuming production. The Engineer will determine resolution for failures which may include requiring removal and replacement of failing material with new asphalt concrete pavement mixture.

Table 2

Operational Tolerance & Minimum Testing Frequency

Description	Test Method	Allowable Difference from JMF Target	Minimum Testing Frequency
Asphalt Content, %	Tex-236-F	± 0.5	1 per day
Theoretical Maximum Spec. (Rice) Gravity	Tex-227-F	N/A	1 per day
Laboratory-Molded Density, %	Tex-207-F	± 1.0	1 per day
Hamburg Wheel-tracking Test , 50°C, 10,000 cycles, mm	Tex-242-F	N/A ¹	1 per week
Boil Test	Tex-530-C	N/A ²	1 per day
Air Voids (4% to 9%)	Tex-207-F	N/A ³	1 per day

1. Hamburg values must not exceed 12.5 mm in 10,000 passes, unless otherwise directed.
2. Compare with sample from mix design to determine amount of stripping.
3. In-Place Air voids should be between 4% and 9%.

A. Mixture Testing. Sample the recycled mixture for testing in accordance with Tex-222-F. For Hamburg Wheel-tracking test, sample prior to compaction.

B. Asphalt Recycling Agent. Meet the requirements of Item 300, “Asphalt, Oils, and Emulsions,” Table 12, “Recycling Agent and Emulsified Recycling Agent.” Unless otherwise directed, obtain a sample from each transport in accordance with Tex-500-C prior to unloading into the contractor’s storage units. Deliver the samples to the Engineer

for testing. The Engineer will test at least one sample per project for specification compliance.

C. Total Asphalt Binder Content. Make asphalt recycling content changes based upon mix design recommendations for varying roadway conditions in order to meet the requirements in Table 2.

D. New Hot Mix Asphalt. Control the quantity of new hot-mix asphalt added to the recycled mix from haul tickets to within 5.0% of the target JMF.

E. Depth of Recycled Material. Maintain the required nominal depth on both outside vertical faces and in the center of the recycled area. Manually measure and report to the Engineer recorded depths each 1/4 mile, measured from the bottom of the mill pass to the top of the surface placed.

F. In-Place Air Voids. The Engineer will select and provide the Contractor random numbers for all placement tests. Unless otherwise shown on the plans, obtain two roadway specimens at each random location determined in accordance with Tex-225-F for in-place air void determination. The Engineer will measure air voids in accordance with Tex-207-F and Tex-227-F. Before drying to a constant weight, cores may be pre-dried using a Corelok or similar vacuum device to remove excess moisture. The Engineer will use the average air void content of the two cores to calculate the in-place air voids at the selected location.

G. Ride Quality. Use Surface Test Type A to evaluate ride quality in accordance with Item 585, "Ride Quality for Pavement Surfaces," unless otherwise shown on the plans.

6. Measurement. Hot in-place recycling of asphalt concrete surface will be measured by the square yard. The dimensions for determining the surface areas are established by the depths and widths shown on the plans and the lengths measured at placement.

Recycling agent will be measured at the applied temperature by the gallon from strap depths measured from the calibrated strap stick for each load or other automated means approved by the Engineer.

New hot-mix asphalt concrete will be measured by the ton of composite mix, which includes asphalt, aggregate, and additives. Measure the new hot-mix on scales in accordance with Item 520, "Weighing and Measuring Equipment."

7. Payment. Hot in-place recycling of asphalt concrete surfaces will be paid for at the unit price bid for "Hot In-Place Recycling of Asphalt Concrete (Surface)" of the depth specified.

Asphalt recycling agent will be paid for separately at the unit price bid for "Hot In-Place Recycling of Asphalt Concrete (Recycling Agent)."

New hot-mix asphalt concrete will be paid for at the unit price bid for "Hot In-Place Recycling of Asphalt Concrete (Mix)."

This price is full compensation for the removal and processing of the existing pavement; for preparing, hauling, and placing materials; for all freight involved; for all manipulations, including rolling and brooming; and for all labor, tools, equipment, and incidentals necessary to complete the work. This price also includes any surface treatment that is allowed in the plans but not required to complete the above work.