Cold In-Place Recycling of Low-Volume Roads

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The stabilization and recycling of an existing roadway pavement structure is not a new process. This procedure has been carried out by using various types of equipment such as rippers, hammermills, pulvimixers, motor graders, and mix pavers for cold, in-place recycling projects. In recent years, however, cold planers have begun to be used to pulverize the existing pavement layers and even to mix in the new asphalt binder material. The efficiency of the cold planer and mixer operation makes it economically attractive for the process of cold, in-place recycling of low-volume roads. Several factors need to be considered when a project is set up for in situ cold recycling. Mix design, which includes chunk size and material gradation as well as asphalt binder type and amount, must be determined. Laydown requirements must be decided. Finally, an economic analysis should be carried out to compare the costs and savings of this method of pavement rehabilitation with other alternative pavement maintenance strategies.

The vast majority of the highway system in the United States and throughout the world carries relatively low volumes of traffic. These rural routes, sometimes called "farm-to-market" roads, have been built up over the years by using readily available, cheap local aggregates. They have been constructed to minimum design standards, both geometrically and structurally. But this secondary highway system serves an extremely important function--moving people and goods to and from the rural and urban areas.

Many miles of these roadways are still aggregate surfaced. The riding surface often becomes dusty in dry weather and muddy in wet weather. The pavement is maintained by periodic shaping with a motor grader to reprofile the aggregate and to correct the washboarding that often occurs. As the traffic volume increases on a particular roadway, several construction techniques are used to provide a dustless surface. One of these methods is the in-place stabilization of the existing aggregate material. The second is the placement of an asphalt-treated wearing surface. Either of these two processes can be done individually or they can both be accomplished on a single roadway.

The initial treated wearing surface on a previously untreated aggregate-base roadway may be a single or double surface treatment (layers of asphalt and cover aggregate). After some years under traffic, an additional surface treatment might be placed. As traffic volumes continue to increase and as greater structural strength is required to carry the applied loads, a cold-mix or hot-mix wearing surface may be placed. Thus, gradually, an existing aggregate-surfaced roadway is upgraded to carry greater amounts of vehicles by adding asphalt-treated wearing surfaces. As failures occur in these pavement structures in the form of soft spots, cracks, potholes, or distortion, patches are placed and additional resurfacings are constructed.

Since the cost of labor, equipment, and materials has increased, the maintenance effort directed to these low-volume roads has necessarily decreased. The local governmental agency will normally use its available monetary resources to repair a highway that has a high vehicle count before it will spend the money to maintain a roadway that carries only low volumes of traffic. Thus, with the passage of time and traffic, these low-traffic-volume pavements have deteriorated and are now in need of repair, resurfacing, or reconstruction.

STABILIZATION AND RECYCLING PROCESS

In the past, it was relatively easy to maintain an aggregate-surfaced roadway. All that was required was an occasional shaping of the roadway by using a motor grader. If soft or low spots occurred in the roadway, new aggregate was added and compacted and the roadway was reopened to traffic. Placement of asphalt-treated wearing surfaces complicated the maintenance procedure, however. If patching or additional resurfacing was not able to correct the pavement deficiency, it was often necessary to rip up the thin asphalt-treated layers and then stabilize the aggregate-base materials. The equipment available to do this stabilization (or recycling) work was of limited capacity for in situ type reconstruction projects.

Stabilization of existing aggregate materials in a pavement structure is not a new process. This method, used by the Romans to construct portions of their vast highway network, allows the strength of the roadway materials to be increased by blending a binder agent into the existing aggregate. Many different materials can be stabilized, including crusher-run aggregates, bank-run gravels and sands, beach and wind-blown sands, cinders, and various waste materials. Depending on the type of material to be stabilized, several different binder agents can be used: asphalt, including asphalt cement, foamed asphalt, cutback asphalt, and asphalt emulsion; portland cement; sodium chloride; calcium chloride; fly ash; and lime (1-3).

The stabilization process today can really be termed a recycling process when the existing roadway pavement materials are incorporated into the stabilized (recycled) pavement layers. Two methods are available to recycle these materials--central-plant recycling, either hot or cold, and in-place cold recycling. Each of these two processes has its own inherent advantages and disadvantages.

The primary advantage of central-plant recycling of low-volume roadways is related to the uniformity of the recycled mixture (4). Existing roadway materials that are variable in gradation, asphalt content, or other properties can be segregated into various stockpiles. The different aggregates can then be blended together in the proper proportion to produce a more uniform quality in the recycled mix. The mixing process usually is accomplished in a pugmill-type plant, either permanent or portable.

The main disadvantage to the central-plant recycling is the cost of hauling the reclaimed material from the construction site to the plant and then hauling the recycled, stabilized mixtures back to the roadway to be placed. This cost, in today's era of high fuel costs and limited financial resources, can be saved by processing the material in place.

For in-place stabilization, the existing pavement layers are recycled where they lie and there is no need to load the materials, haul the aggregates to the central plant and back, and spread the recycled mix back on the roadway area. This major cost advantage, however, is offset somewhat by possible reduced quality of the recycled mixtures if the consistency of the in-place pavement layers is variable. In addition, it is normally easier to add any required new, untreated aggregate in the central-plant operation than it is in an in-place recycling process.

Most in-place asphalt stabilization and recycling projects done recently have encompassed a relatively

Figure 1. Chunk size of reclaimed asphalt-treated material after one pass of a hammermill.

Figure 2. Pulvimixer adding asphalt binder to pulverized reclaimed material.

common series of operations (5,6). These can be described as (a) the ripping or scarification of the existing pavement layers, (b) the reduction in size of the asphalt-treated or chemically bound aggregate particles, (c) the windrowing of the pulverized material, (d) the mixing in of the new asphalt binder, (e) the spreading of the recycled material, and (f) the compaction of the finished asphalt-treated layer.

Scarification

Generally a motor grader or bulldozer equipped with ripper teeth is used to scarify the existing pavement layers. This process usually is quite efficient, especially if the asphalt-treated layers are relatively thin [3 in (76 mm) or less]. The first major difficulty with this ripping operation is the large chunks of asphalt-bound material that are created. The second major problem is the tendency for the ripper teeth to dig deeper than desired into the existing pavement layers. This not only disturbs the underlying aggregate base layers, but increases, sometimes dramatically, the amount of material that must be asphalt treated in the stabilization and recycling process. The intrusion of the scarification teeth into the layers not scheduled for treatment thus increases the nonuniformity of the recycled material.

Pulverization

Several different types of equipment can be used to reduce the size of the chunks produced during the scarification process. Among these are hammermills and pulvimixers (7). The purpose of this equipment as it passes through the ripped material is to crush the reclaimed material down to the point where it passes a certain sieve size. This equipment, however, has two basic limitations. First, it is limited in width. Most hammermills and pulvimixers can only cut a windrow or width of material 4-5 ft (1.3-1.6 m) wide. Second, this equipment usually requires multiple passes (sometimes as many as six to eight) before the required chunk size for the reclaimed material can be obtained. Even after many passes, occasional oversized pieces of asphalt-treated aggregate will remain, depending on the type of material being pulverized, the condition of the existing pavement layers, and the top size required for the reclaimed material. Figure 1 shows a typical material gradation after the first pass of a hammermill through a scarified pavement layer.

Windrowing

After the reclaimed material, both asphalt treated and/or aggregate base, is reduced to the proper top size, the pulverized material is normally windrowed. This operation is usually carried out by using a motor grader. The use of a windrow makes it easier for the mixing equipment that follows the grader to apply the required binder material.

Mixing

A pulvimixer-type piece of equipment is customarily used to add the asphalt material to the pulverized aggregate. One make of pulvimixer is shown in Figure 2. This type of equipment can have single or multiple shafts, each containing multiple mixing tines or paddles. Depending on the amount of asphalt material to be added to the scarified reclaimed material, the asphalt may be added all at one time (one pass of the machine) or in several passes. Any type of asphalt material--asphalt cement, foamed asphalt, cutback asphalt, asphalt emulsion, or recycling agent--can be added through the pulvimixer from the tank truck or the asphalt distributor. In recent years, emulsified asphalt has been the primary binder agent used in most cold, in-place recycling projects (8). The primary decisions to be made during the mixing operation revolve around the type of aspalt binder to be added and the amount of material to use. Again depending on job conditions, one or more passes of the pulvimixer may be required to properly distribute and mix the asphalt binder with the reclaimed material. Because of this multipass operation and because of the variability of this binder addition process, the uniformity of the binder distribution is sometimes poor.

Spreading

The spreading or grading operation is normally done with a motor grader. This piece of equipment levels the recycled mixture and provides the correct cross slope to the roadway. Occasionally a conventional

Figure 3. Cold planer feeding reclaimed material directly into mix paver.

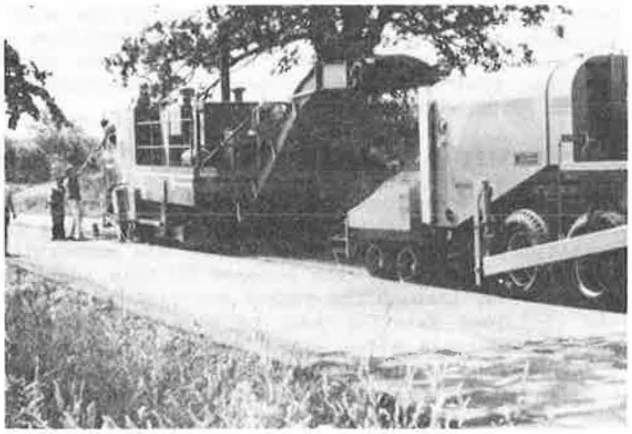


Figure 5. Loading reclaimed material into mix paver.

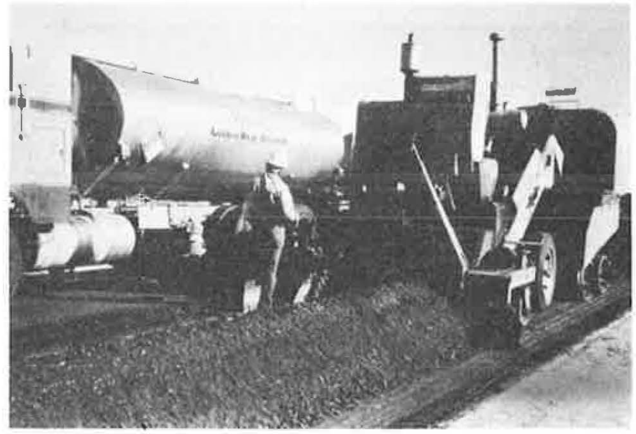
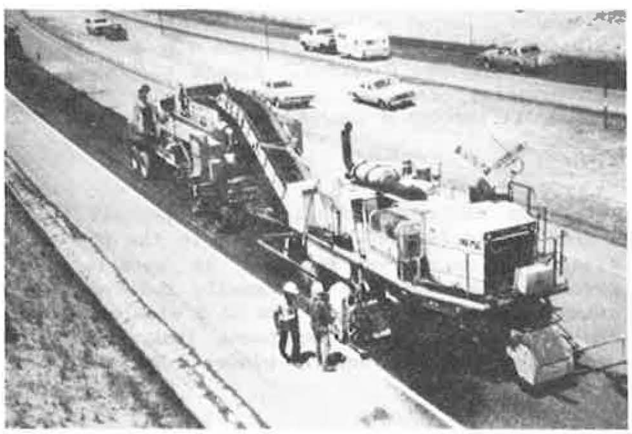


Figure 4. Cold planer feeding reclaimed material into towed screen and roll crusher.



asphalt paver is used to place the treated material. If a paver is used, the motor grader windrows the recycled mix. The windrow is loaded into the paver hopper by means of a pickup machine attached to the front of the paver. The recycled mix is then spread across the width to be paved in a way similar to that for a normal hot-mix asphalt-concrete operation.

Compaction

Conventional compaction equipment--static steel-wheel rollers, pneumatic tire rollers, and vibratory rollers--is used to provide the required density to the cold, recycled mixture. The number of passes needed of each roller depends on the workability and properties of the recycled mix, the thickness of the layer placed, the type and weight of roller used, and environmental conditions. Normal compaction procedures are used even though the cold-mixed material may be somewhat stiffer than hot-mixed asphalt concrete. The density of the cold, recycled mixture is usually less than that of a hot-mix material.

COLD PLANING AND COLD RECYCLING

A modern cold-planing machine can also be used as part of the cold in-place recycling process. Its application is in three primary areas: (a) to pulverize and size the existing asphalt-treated (asphalt-bound) pavement layers, (b) to break up and blend in the underlying untreated aggregate base or subbase courses, and (c) to mix in the asphalt binder agent during the pulverization operation. For the pulverization pass, no modifications are needed to the standard cold planing and milling equipment from its normal configuration for conventional pavement-removal operations. For the mixing operation, an asphalt pump and meter system and asphalt spray bar must be added to the machine.

Pulverization and Mixing Train

Cold-planing machines can be used to pulverize the existing asphalt-treated material and untreated aggregate base layers of an existing pavement structure. As these machines became available in the mid-1970s, they began to replace the conventional ripping and crushing equipment as a means to prepare the existing roadway materials for stabilization. The cold planing and milling equipment was used in place of large hammermills and pulvimixers because of its ability to pulverize and size the existing pavement materials in a single pass of the machine.

Initially the pulverized asphalt-treated and untreated aggregate base material that was produced by the cold planers was mixed by using standard mixing equipment such as a pulvimixer or rotary tiller. In August 1978, however, a Barber-Greene RX-75 cold-planing machine was used to feed pulverized material directly to a Midland mix paver. This was the first project, done in Livingston County, Michigan, where the "pulverization and mixing train" concept of cold, in-place recycling was used.

For this project, approximately 4 in (102 mm) of existing roadway pavement was removed and pulverized by using the cold planer. The crushed material was fed by the conveyors on the machine directly into the hopper on the front of the mix paver. This latter machine, which consists of an asphalt storage tank, asphalt spray-bar system, twin-shaft pugmill, and normal paver screed, was used to mix an asphalt cement with the reclaimed material. This operation is shown in Figure 3. The recycled mixture was placed back on the same county roadway by the mix paver and compacted by normal rolling equipment and procedures.

The idea of a pulverization and mixing train was carried one step further on a cold, in-place recycling job in Kansas in 1979. A CMI Rotomill was used to remove and pulverize a 4-in (102-mm) depth of asphalt concrete from a portion of KS-96 in Scott

County (9,10). As the material was being cut, an asphalt-recycling agent was added to the pulverized material through the water system and water spray bar on the planer. This asphalt binder was blended with the reclaimed material during the cutting and pulverization procedure. After it was carried up the loading conveyors on the machine, the recycled mix was windrowed and loaded into a conventional paver by using a pickup machine and then spread across the pavement width. The cold-mixed material was compacted by using conventional rolling equipment.

California's first cold, in-place recycling project that used a cold-planing machine was constructed in the fall of 1979. The project, located on US-395 north of Bishop, called for the removal of 5 in (127 mm) of asphalt concrete (11). On this project, however, the cold-planing equipment was used only to remove and pulverize the existing asphalt layers. The pulverized reclaimed material, windrowed by the cold planer, was mixed by using a Gardner mixer, which added the required amount of recycling agent to the reclaimed asphalt concrete.

California's second cold, in-place recycling project, however, incorporated the concept of the pulverization and mixing train. During the 1981 paving season, another section of US-395 near Bishop was cold recycled. To control the size of the reclaimed material produced by the cold planer, a trailer-mounted screen and small roll crusher were towed by the milling machine. The 3-in depth of existing pavement was pulverized and then passed up the conveyors on the cold planer and across the screen deck. Any reclaimed aggregate less than 1.5 in (38 mm) fell through the screen and directly into a windrow on the planed roadway surface. Any oversized chunks of asphalt concrete were carried over the screen and into the roll crusher. The crushed material then fell onto the same roadway windrow. Figure 4 shows this pulverization and crushing process.

As seen in Figure 5, a pickup machine on the front of a Midland mix paver was used to feed the cold-mix equipment. A recycling agent was mixed with the reclaimed material in the mix paver. The recycled mixture was then placed back on the roadway by the paver.

A similar pulverization-and-mixing-train operation was also done in 1981 on a portion of US-70 east of Globe, Arizona (12). Again for this contract, a cold-planing machine was used to remove and pulverize the existing asphalt-treated and aggregate layers, a towed screen deck and roll crusher were used to size the reclaimed material and crush any oversized pieces, and a mix paver was employed to add and mix the asphalt emulsion and recycling agent and to place the recycled material back on the roadway.

The same type of reclaiming, sizing, mixing, and placing equipment train was used to cold, in-place recycle a number of secondary state highway pavements during the first part of 1982. Among the projects on which this process was used were (a) US-395 near Four Corners in California, (b) CA-178 near Inyokern in California (13), and (c) US-34 in the Rocky Mountain National Park in Colorado. In each case, the cold planer was used only to remove and pulverize the existing asphalt-concrete pavement layers. The asphalt binder agent was not added to the reclaimed material through the cold planer but was added through a separate machine.

Combined Pulverization and Mixing

During the summer of 1980, a Barber-Greene half-lane cold-planing machine was fitted with an asphalt pump and meter system. An asphalt spray bar was installed inside the cutting chamber above the cutting drum and adjacent to the water spray-bar system. The machine was used for cold, in-place recycling of a city street in Aurora, Illinois. This experimental project, which called for the addition of an asphalt emulsion to the reclaimed asphalt-treated material, was set up to determine whether proper mixing of the added binder could be accomplished during the reclaiming and pulverization process. A total depth of 7 in (178 mm) of asphalt-treated material (some old surface treatments, cold-mix layers, and asphalt-concrete courses) was cut and mixed in a single pass of the cold planer through the pavement structure.

Several different types of cutting flights were tried in order to determine the effect of flight design on the cutting and mixing action. Upcutting was initially done; the cutting drum was rotated in such a manner that the teeth cut from the bottom of the pavement layers upward as the cold planer moved forward. Downcutting was also performed; the cutting teeth struck the top of the pavement surface in a downward direction as the machine traveled ahead. A second city street was also cold recycled. Various forward travel speeds of the cold planer were experimented with to determine the effect on chunk size and mixing uniformity. In general, the mixing efficiency of the cold-planer cutting drum and teeth was excellent and a very uniform, well-coated recycled mixture was produced.

Additional testing of the cold planer as a cold, in-place recycling machine was completed during the winter of 1980-1981 in Florida. Experimental sections were constructed on an old abandoned section of highway to determine the effect of the following variables on mixing efficiency and mixture strength: (a) depth of cut, (b) relative thicknesses of asphalt concrete and aggregate base, (c) type of cutting direction (upcut and downcut), (d) forward travel speed, (e) type of added asphalt binder (asphalt cement, foamed asphalt, several types of asphalt emulsion), (f) amount of asphalt binder, (g) amount of added moisture (mixing water), and (h) retention time in the cutting chamber. This experimental work showed that the cold-planing equipment could be used to pulverize an existing pavement material, add the required amount of new asphalt binder agent, mix the reclaimed material and the asphalt binder together, and either windrow the recycled material or spread it across the roadway width.

In September 1981, this modified Barber-Green planer was used on a contract cold-recycling project on US-6 in western Colorado, near the town of DeBeque (14). The plans called for the removal of 2 in (51 mm) of existing asphalt concrete by cold planing. Four different test sections were specified: (a) two called for mixing an asphalt emulsion with a motor grader after pulverization had been accomplished by the cold planer, (b) two required adding an asphalt emulsion through the cold planer during the cutting and pulverization process, (c) two then required spreading and leveling the recycled mix with a motor grader, and (d) two then specified the use of an asphalt paver to place the recycled cold-mix material.

Figure 6 shows the experimental equipment used on this cold-recycling contract. The asphalt pump and meter skid on this cold planer were mounted on the rear of the machine, in place of the loading conveyors. The machine operated primarily in an upcut mode; the asphalt emulsion was added through the asphalt spray bar during the reclaiming operation. The recycled material was left full width behind the machine, ready for minor leveling by the motor

Figure 6. Cold planer pulverizing existing asphalt concrete and adding emulsified asphalt through rear-mounted asphalt pump and meter system.

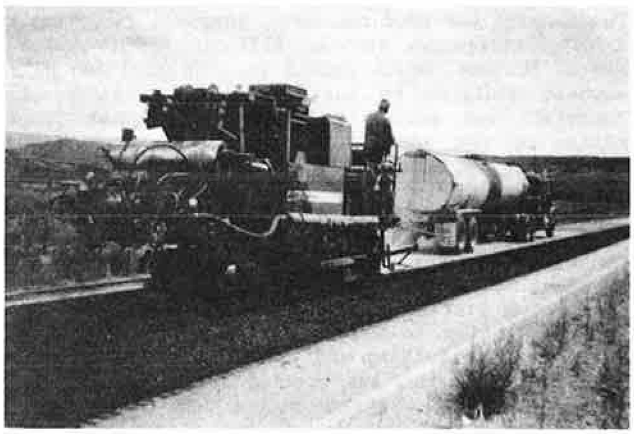
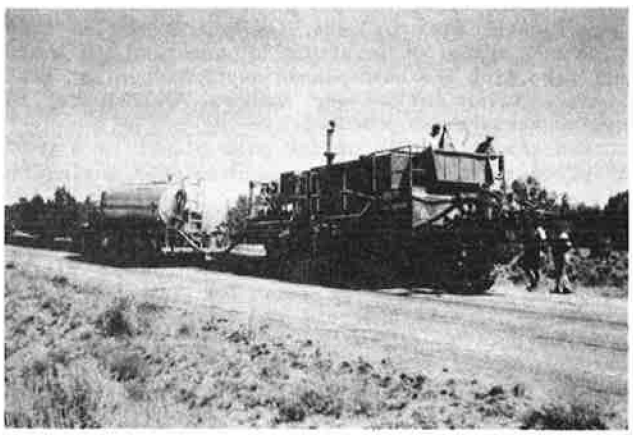


Figure 7. Cold planer pulverizing existing asphalt concrete and adding recycling agent through front-mounted asphalt pump and meter system.



grader and compaction by both a vibratory and a pneumatic tire roller. According to Colorado Department of Transportation reports, the mixing efficiency of the cold planer was excellent, and a very uniform mixture was obtained (14).

The same piece of equipment was used to cold recycle a portion of the 7-ft (2.3-m) wide westbound shoulder on a stretch of Interstate 90 near Madison, Wisconsin, in July 1982. This job called for the addition of an asphalt-recycling agent during the pulverization process. Three inches of existing asphalt concrete were removed, pulverized, and mixed in a single pass of the cold planer. The recycled material was passed out the rear of the planer and was fed into a small conventional paver by using a pickup machine. The recycled mix was compacted by using normal pneumatic tire and vibratory rollers.

Modifications to the pump and meter skid were made to allow the unit to be front mounted on a cold-planing machine; this allowed the loading conveyor to be used, if desired, on the rear of the machine. A commercial version of the skid was installed on a full-lane planer and the equipment was used on a cold, in-place recycling project on NV-319 near Panaca, Nevada, in August 1982. The added asphalt-recycling agent was pumped to the machine from a distributor/tanker, which was either pushed or pulled by the cold planer.

Approximately 3 in of old asphalt pavement were removed by the planer; the cutting drum operated in a downcut mode. Specifications called for a gradation that had 100 percent passing the 1.5-in (38-mm) sieve. This was basically accomplished, with only an occasional oversized piece, by one pass of the cold planer operating at a forward travel speed of more than 30 ft/min (9.8 m/min). The recycling agent was sprayed on the reclaimed material as it was being pulverized. The material was then transferred up the short loading conveyor and deposited in a windrow behind the machine, as shown in Figure 7.

Placement of the recycled asphalt-treated mixture was again completed by a conventional asphalt paver fitted with a pickup machine on the front. No major problems were encountered during this process. A vibratory roller, operated in a static mode, and a pneumatic tire roller were used to obtain the required level of density of the cold, recycled mixture.

DISCUSSION OF RESULTS

The various cold, in-place recycling projects described above were carried out on roadways picked for rehabilitation by the individual governmental agencies responsible for their performance and maintenance. Most of the projects were not constructed on true low-traffic-volume highways. The thicknesses of the asphalt-bound wearing surfaces, in particular, are generally greater than those normally found on roadways that carry less than 100 vehicles per day. The stabilization and recycling processes used, however, are applicable to the cold, in-place recycling of any pavement structure in which the combined thickness of the asphalt-bound and untreated aggregate layers to be recycled is generally less than 6 in (152 mm).

Advantages of Cold Planing and Cold Recycling

The use of a cold planer to both pulverize an existing pavement structure and mix in the new asphalt binder agent appears to have several distinct advantages in a cold, in-place recycling operation. One important factor is that this type of equipment can accurately control the depth of cut. This is in sharp contrast to a stabilization and recycling process in which a ripper or scarifier tooth is used to rip the existing pavement layers. Equipped with grade and slope controls, the cold planer can accurately remove any depth of asphalt-treated and/or aggregate base material without disturbing the layers below the courses specified for recycling and can correct the geometry of the roadway at the same time.

A second factor is that the cold planer is capable of cutting up to 7 in or more in a single pass, depending on the type and condition of the asphalt-treated material being cut, pulverized, and mixed. This is due to the high-horsepower engines on the cold planers and the efficiency of the rotating cutting drum and cutting teeth. These machines can pulverize the existing pavement materials to the proper gradation and top chunk size in a single pass instead of multiple passes.

A cold planer equipped to add the asphalt binder agent during the pulverization process can accurately introduce the required amount of binder into the reclaimed aggregate. This is because the pump and meter system used is similar to that employed for many years on asphalt batch and drum-mix plants. These components are highly reliable and precise in providing the correct amount of binder per unit of surface area and depth.

A fourth advantage of this type of cold-recycling process is related to the completeness of the mixing process. As determined from both the experimental and actual contract projects completed to date, the coating obtained when the asphalt binder material is introduced during the pulverization process is uniform, both across the width of the cut and throughout the depth of cut (9,14). All mixing can be done in one pass of the machine--the total amount of new asphalt can be applied at one time and complete mixing is accomplished after only one pass. Additional mixing passes with the cold planer do not improve the excellent uniformity of the coating already obtained.

Properly operated, a cold-planing machine can produce a cold, in-place recycled pavement with a minimum of additional equipment. In contrast to a more conventional stabilization and recycling process, only one machine is needed to reclaim (rip) the existing pavement layers, pulverize them, and mix in the new binder material. The ripping equipment is not needed, the hammermill or pulvimizer equipment is not needed, and the pulvimixer or mobile mix paver is not needed. If the cold planer is provided with spreading flights, the recycled material can be distributed out the back of the planer to the same full width as that removed. This eliminates the need for a pickup machine and paver to place the recycled mix. All that is necessary would be a motor grader to lightly blade and level the recycled mix. Compaction operations would be the same in either case.

Cold, in-place recycling could be accomplished with one cold planer, one grader, and the appropriate number of rollers. This simple process, in which the cold-planing and milling machine rips the existing pavement, pulverizes the chunks of asphalt material, and spreads the completed recycled mix, is the least costly way to produce a cold, in-place recycled pavement structure.

An additional advantage concerns traffic control and traffic disruption. Because most cold, in-place recycling work on low-volume roads is done under traffic, by minimizing the amount of equipment needed to complete the recycling process, the length of the work zone can be reduced. Depending on the type of asphalt binder added to the reclaimed material, a stretch of pavement can easily be pulverized, mixed, spread, and compacted in less than 1 h by using the concept of combined pulverization and mixing with a cold planer. The single-pass operation greatly decreases the interference with traffic and allows the minimum length of pavement to be closed for recycling for the minimum amount of time.

Mix Design Questions

Two questions in particular need to be addressed when specifications are written for a cold, in-place recycling project. The first concerns the maximum chunk size of asphalt-treated reclaimed material that will be allowed in the recycled mixture and the gradation requirements for that material below the top size. The second deals with the type and amount of new asphalt binder agent that is to be added to the reclaimed material.

Chunk Size and Gradation

To date, most of the specifications used on the cold, in-place recycling projects have been quite restrictive concerning the top size of the chunks of asphalt-treated reclaimed material allowed in the recycled mixture. Some have called for 100 percent of the reclaimed and recycled material to pass the 1-in (25-mm) screen. It is extremely difficult for any pulverization equipment--cold planer, hammermill, or pulvimixer--to achieve this gradation requirement.

The chunk size obtained during the pulverization process depends on several variables. One of the most significant is the condition of the existing pavement. If the existing surface is structurally sound, a cold planer can produce a relatively small, uniform chunk size. If, however, the roadway is alligator (fatigue) cracked, chances are that some oversized pieces will be produced, particularly if an upcutting mode of operation is used. Further, if the depth of cut is near a horizontal joint line between different layers or courses of asphalt-treated materials, a greater amount of oversized chunks will be created.

Chunk size also depends on the aggregate size used in the original aggregate base and asphalt-treated layers. It is hard to meet a specification calling for 100 percent passing the 1.5-in sieve when the existing pavement layers contain 2-in top-size aggregate pieces.

To some degree, chunk size will also depend on the depth of the layer being stabilized. Thicker cuts of existing pavement will tend to produce chunks of greater size.

Occasionally a specification will call for some range or percentage of aggregate to pass some intermediate screens or even require a given amount of reclaimed and recycled material to pass the No. 200 (0.074-mm) sieve. It is practically impossible to predetermine what the gradation of the reclaimed material will be in a cold, in-place recycled mixture. Too many variables affect the intermediate and smaller aggregate sizes. Thus a gradation specification should require only that some maximum amount of reclaimed and recycled material pass the No. 200 sieve. This latter number should be carefully chosen, depending on the amount of the material in the original pavement layers, the type of pulverization process, and the need to restrict the amount in order to obtain adequate recycled mix stability.

In general, a specification for a cold, in-place recycled mixture needs to have some maximum chunk-size requirement. A value of 100 percent passing the 4-in (102-mm) screen would be reasonable. Second, a limit is needed to control the nominal top size of the reclaimed aggregate chunks. A good value of this property might be 97 percent passing the 1.5-in sieve. By using these two specification limits, the contracts would allow for the occasional oversized piece without being unduly restrictive. If an upper limit is needed on the amount of material passing the No. 200 sieve, a value of 12 percent would be reasonable in most cases, depending on the original aggregate characteristics.

In typical cold-planing work on existing asphalt-concrete pavement layers, the increase in the amount of material passing the No. 200 sieve is slight, usually in the range of 2-3 percent. Thus, if a cold-recycling job consisted of only reclaiming old asphalt-concrete material, a 12 percent upper limit on the recycled mixture gradation might be quite liberal for the No. 200 sieve. If, however, a sand-asphalt mixture and a sand-subbase layer were being jointly reclaimed and recycled, the 12 percent limit for this sieve might well be too restrictive and impossible to meet. Since cold planing does increase the fines content of the reclaimed material, even only slightly, this fact must be considered when the gradation limits for the reclaimed and recycled material are set. The mix design values for aggregate gradation produced during the cold-recycling process must reflect what materials are present in the roadway and not what the designer considers to be optimum values.

The material being reclaimed and recycled in a cold, in-place process is normally variable in condition, composition, and characteristics. It makes little engineering or economic sense, therefore, to expect the material to be consistent and uniform in composition or gradation after it has been reclaimed and recycled. Allowance must be made in the specification for the inherent variability of the cold, recycled material.

Type and Amount of New Binder

There are several distinctly different schools of thought concerning the amount and type of binder agent to be added to the cold, recycled mix. One school revolves around the theory that all the asphalt that has coated the reclaimed particles can be rejuvenated and reused. The second school says that, in a cold mix, the old, aged binder is inert and cannot be counted on as binder in the recycled mix. Then there is the group that believes that some of the old asphalt can be recycled, but not all of it.

There is now a wealth of research on the use of recycling agents to rejuvenate the aged asphalt cement in a recycled hot-mix material (15-17). There is a definite lack of comparable research work on the benefit of these same additives when used in a cold, recycled mix (18). If the old binder can be rejuvenated and reused, the amount of new binder needed would be reduced proportionately. If the recycling agents do not perform as predicted, however, premature failure of the recycled pavement layers could occur, primarily due to lack of an adequate asphalt content in the mix.

It is beyond the scope of this paper to determine which school of thought or theory is correct. It is also not germane to discuss which type of asphalt binder--asphalt cement, foamed asphalt, cutback asphalt, asphalt emulsion, or recycling agent--should be specified for the recycled mix. It is necessary to point out, however, that the effective binder content of the recycled material will govern the ultimate performance of the mixture under traffic. This criterion is significantly more important than the gradation on the chunks of reclaimed material in the cold, recycled mix. More research needs to be conducted soon to determine the value of the old, aged asphalt under ambient temperature conditions as binder in the new, recycled mix.

Laydown Requirements

The majority of the cold-planing and recycling projects completed (summer 1982) have had requirements for placement of the recycled mix by asphalt paving machines. Automatic grade and slope controls for the paver have been specified on several projects. Such a requirement--for the use of the paver--is really unnecessary and costly. The output of the cold-planing machine, in terms of tons per hour or square yards per hour, is much less than the capacity of the average-size paver. By necessity, therefore, the paver and its crew spend a great part of the day waiting for the planer to produce enough material for it to lay.

Because of the unknown factors of mix design, which can significantly alter the level of performance of the cold, recycled material, a wearing surface should always be placed over the recycled mixture. This wearing course can be a single or double surface treatment, a layer of cold-mixed asphalt, or a layer of asphalt concrete. If the wearing course is to be placed, and it should be, it usually does not make economic sense on a low-traffic-volume roadway to require the cold, recycled mix to be placed only by a paver.

If the cold planer is equipped to add the required asphalt binder agent, it can place the recycled mix either in a windrow or full width across the cut. In the former case, a good motor-grader operator can manipulate the mix and spread it out across the roadway with multiple passes of the equipment. After some effort, a reasonably smooth and true-to-grade recycled mix layer can be obtained. Slight changes in the original longitudinal and transverse profile of the roadway can be accomplished with this method of operation.

In the latter case, however, the amount of work that the motor grader needs to do to level the mix is minimal. This is because the cold planer and mixer can be equipped with automatic grade and slope controls similar to those used on the asphalt paver. Thus, the mat of recycled mix placed full width by the cold planer by using spreading flights can be laid to a reasonably consistent grade and cross slope. It must be remembered, however, that the cold planer has no storage or hopper capacity and can therefore not carry any significant amount of reclaimed and recycled mix for any distance. Thus any long swales or dips in the original pavement structure will be reproduced in the recycled mat; the original longitudinal and transverse profile of the roadway cannot be altered to any significant degree.

The same fact is true, however, even when a pickup machine and paver are used to place the mix. The amount of recycled material in the windrow at any given point is directly proportional to the amount of material present, and then removed, from the existing pavement structure at a point some short distance ahead of the windrow reference point. Thus the paver, because of the lack of extra available material, will not remove any long swales or dips in the original roadway either. This fact then eliminates much of the current reasoning behind the requirement for an asphalt paver to lay the recycled cold-mix material. The cold planer itself, together with minimal touch-up help from a motor grader, can place a perfectly acceptable mat without the need for and the cost of an asphalt paver.

Economics

The only reason to recycle a given stretch of roadway is economics. It should be less expensive to reuse some or all of the existing pavement materials than it is to use all new materials or recycling should not be done. Many factors, however, must go into the economic calculations, some of which are easy to quantify and some of which are extremely difficult to estimate accurately (19).

Cold, in-place recycling, because it reuses the pavement materials already on site, is usually a less expensive way to rehabilitate a given section of highway. Adding a new asphalt binder to the reclaimed material after it has been pulverized increases the strength and load-carrying ability of the recycled pavement layer. Thus the roadway structure can be stabilized and upgraded at minimal cost without the need and cost of hauling the existing materials to a central plant for processing and then returning them to the roadway. It must be kept in mind, however, that the quality of the cold, in-place recycled mixture is dependent on the quality and condition of the materials in the existing pavement. Such a mixture, therefore, will never be equal in structural strength to a recycled hot-mix material.

Each section of a low-volume roadway scheduled for maintenance or reconstruction should be subjected to an engineering and economic analysis for various rehabilitation strategies (19). One of the alternatives considered should be that of cold, in-place recycling.

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Use of Asphalt Emulsion and Foamed Asphalt in Cold-Recycled Asphalt Paving Mixtures

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Increased interest in improving the quality of cold-recycled asphalt paving mixtures has made it necessary to understand the behavior of these mixes better. This laboratory study investigates the long-term behavior of cold-recycled asphalt paving mixtures by using asphalt emulsion and foamed asphalt as the added binders. An artificially aged paving mixture was used to make the recycled mixes for this study. Specimens of the recycled mixes were compacted with the gyratory testing machine. The resilient modulus, Hveem stabilometer R-value, and Marshall stability were obtained on the compacted recycled mixes at various levels of compactive effort, added binder, testing temperature, and curing time. Results indicate that most of the rejuvenating action of the added binder on the old binder takes place during the compaction process. The binders of the recycled mixes that undergo the initial softening during the compaction process generally increase in stiffness with increasing curing time. The recycled mix with foamed asphalt added had properties comparable to those of the mix with asphalt emulsion added. However, slightly more added binder is needed when foamed asphalt is used. The structural performance of these recycled mixes as a stabilized base in a typical low-volume road was also evaluated and compared with that of a standard asphalt concrete by using a linear elastic multilayer analysis.

The recycling of asphalt pavement is the process of reusing a deteriorated asphalt pavement material in a functionally new pavement. An existing asphalt pavement material usually contains a hardened asphaltic binder and a deteriorated aggregate and has lost such desirable characteristics as stability, flexibility, and durability. The fundamental process of asphalt pavement recycling involves the addition of rejuvenating agents to soften the hardened old asphaltic binders and the addition of virgin aggregates to upgrade the deteriorated aggregates. Basically, it involves (a) removing the old pavement material from the road; (b) remixing it, when necessary, with additional virgin aggregate, a virgin binder, or a rejuvenating agent; and (c) recompacting it. The process can be carried out either hot or cold. In a hot-recycled mix, the blending of the old binder and the virgin binder is relatively more homogeneous. In a cold-recycled mix, the virgin binder or rejuvenating agent tends to adhere to the old material (old aggregate coated with old binder) and to form a thin film around it. The diffusion of the virgin binder or rejuvenating agent into the old binder could be a function of time, temperature, and additional traffic compaction (1,2). This diffusion process could greatly influence the behavior of a recycled material, and thus a knowledge of its long-term behavior is very important in designing a recycled mix.

Asphalt emulsion is a commonly used added binder in cold recycling. Recently, increased interest has also been shown in using foamed asphalt as an added binder in cold recycling. This laboratory study investigates the long-term behavior of the cold-recycled asphalt paving mixtures that use asphalt emulsion and foamed asphalt as the added binders. The study has the following objectives: