NUMBER 8

TECH TOPIC

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RECYCLING ASPHALT PAVEMENTS— A STRATEGY REVISITED

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Introduction

Pavement recycling is a logical and practical way to conserve our diminishing supply of construction materials and to help reduce the cost of preserving our existing pavement network. When properly designed and constructed, recycled pavements have been found to perform as well as pavements built with all new materials[1,2]. The asphalt pavement industry recycles approximately 73 million tons of material annually, which is more than twice the combined total for recycled paper, glass, plastic, and aluminum[3].

Several recycling techniques, such as hot mix recycling, hot in-place recycling, cold mix recycling, cold in-place recycling, and full depth reclamation, have evolved over the past 35 years[4]. In-place recycling not only reduces the use of new materials but also reduces emissions, traffic, and energy associated with the transport and production of these materials.

As with new pavement construction, well thought-out materials evaluation, mix design, structural design, and QC/QA procedures and specifications are all important elements of successful recycling projects. Technical assistance from industry organizations or experienced highway agencies is available to local agencies seeking guidance on the selection of appropriate recycling strategies.

Background

Pavement recycling is not a new concept. In the 1970s, interest in pavement recycling was fueled by an oil embargo, which drove asphalt prices higher. Major advances in the development of heavy duty equipment and construction procedures have been a part of the recycling evolution. Powerful milling equipment was developed so that contractors could reclaim material from distressed asphalt pavements and combine it with virgin aggregate and asphalt. Hot mix asphalt plants were modified to handle reclaimed asphalt pavements (RAP). Mix design, structural design, and construction practices were altered, where needed, to accommodate the use of RAP.

Interest was rekindled in the early 2000s in pavement recycling as the hot mix asphalt industry once again faced rapidly rising asphalt costs along with diminishing supplies of high quality aggregate. Among the factors which make pavement recycling attractive are cost effectiveness, material conservation, and ecological considerations. The use of RAP in asphalt mixes helps reduce costs, conserves asphalt and aggregate resources, and limits the amount of waste material going into landfills.

Asphalt Recycling Methods

Hot Mix Recycling is the most common method of recycling asphalt pavements. It involves combining RAP with new or "virgin" aggregate, new asphalt binder, and/or recycling agents* in a central hot mix plant to produce a recycled mix. The amount of RAP allowed in a recycled mix and guidelines as to where the recycled mix can be used in the pavement structure varies by agency. Some agencies routinely allow 15% or less RAP while others permit larger amounts of RAP. Higher RAP concentrations require adjustments in mix design and binder selection. Suggested guidelines relative to RAP content in a recycled mix are as follows[5]:

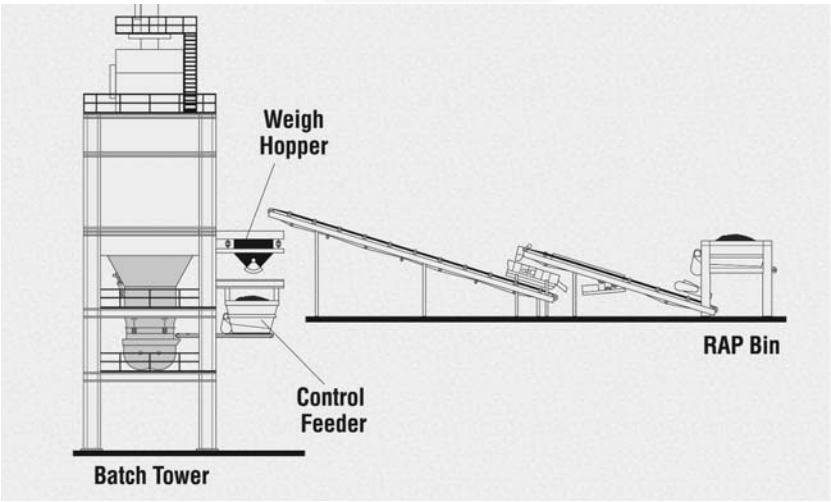
- **15% RAP or less:** PG binder is the same as that used in a virgin mix.
- **15-25% RAP:** PG binder should be one grade lower on both high and low temperature end, i.e. PG 64-16 rather than PG 70-10.
- **>25% RAP:** Test and blend the recovered asphalt from RAP with virgin asphalt as part of the design process to determine the amount of RAP to use.

* A recycling agent is a petroleum-based oil used to soften the aged asphalt in the reclaimed mix.

For higher levels of RAP, it is critical that proper material evaluation, mix design, construction, and quality control issues are addressed. A recent publication by the National Asphalt Pavement Association (NAPA) provides an excellent guide for designing hot mix asphalt pavements with high RAP content[6].

Once RAP has been hauled to a central plant, it is processed and stored for future use. Processing may include crushing and screening the RAP prior to stockpiling. When large quantities of RAP come from different sources, the stockpiles should be separated and identified by source. However, space constraints and limited

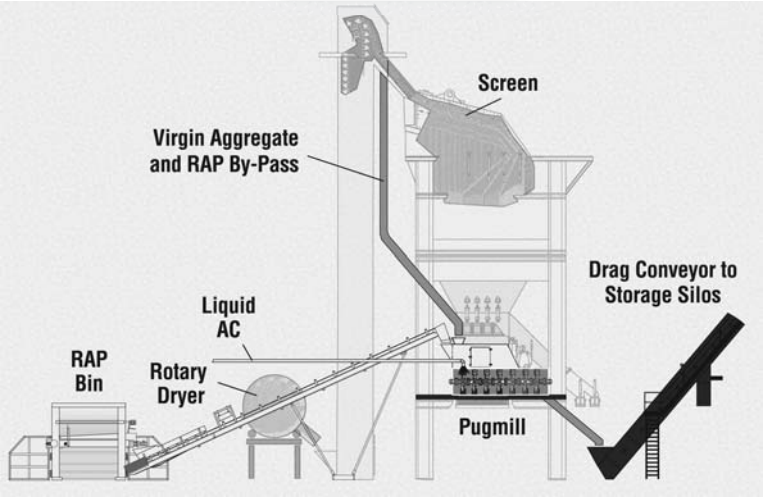
FIGURE 1A



RAP Delivery System for Batch Plants

Figure courtesy of Astec, Inc.

FIGURE 1B



Batch Plant with Pugmill Mixer

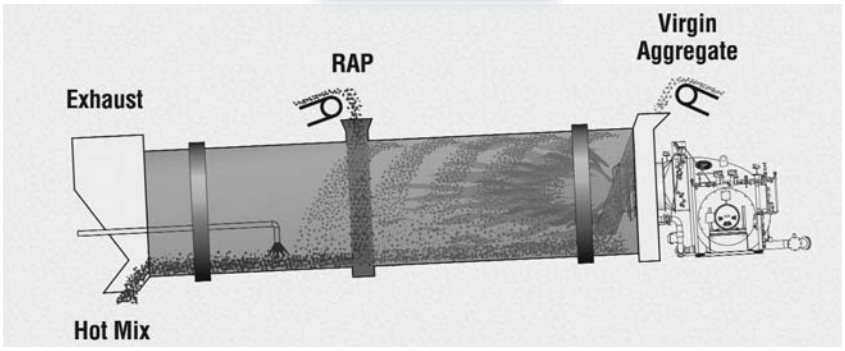
Figure courtesy of Astec, Inc.

quantities of RAP from some sources often result in a composite or blended stockpile that needs to be properly characterized. Separating the RAP into different sizes will minimize segregation of RAP particles and allow greater flexibility in adjusting RAP content to meet required final aggregate gradation. Since moisture in RAP can have a major effect on the amount of RAP used or the quality of the recycled mix, it is important for the contractor to monitor RAP moisture and utilize best management practices to minimize moisture. Information on the processing and handling of RAP can be found in another NAPA publication on recycling of hot mix asphalt pavements[7].

How RAP is combined with virgin aggregate and asphalt to produce a recycled mix depends largely on the configuration of the hot mix plant. A RAP delivery system for typical batch plant operations is shown in Figures 1A and 1B. RAP is added directly to the mixer in a drum mix plant (Figures 2A, 2B, and 2C). The point at which RAP is added to the drum mixer depends on the type of mixer being used (parallel flow versus counter flow versus double barrel) and whether or not a separate coater is included in the drum mix operation[8].

Once the recycled mix has been produced, it is either sent to storage silos for future delivery to a job or it is immediately transported, placed, and compacted with conventional hot mix equipment at the project site. No special techniques are required to handle recycled mix. However, the paving crew should be aware that the recycled mix may be delivered at a slightly lower temperature than a virgin mix to prevent overheating the mix at the plant. As a result, the time allowed for compaction of the recycled mix may be slightly reduced.

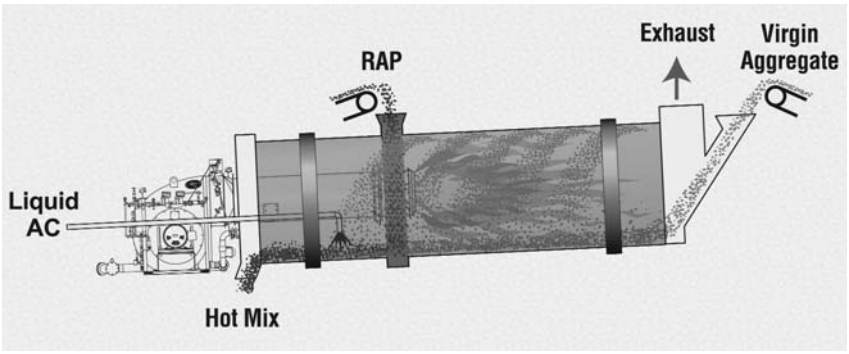
FIGURE 2A



Parallel Flow Drum Mixer

Figure courtesy of Astec, Inc.

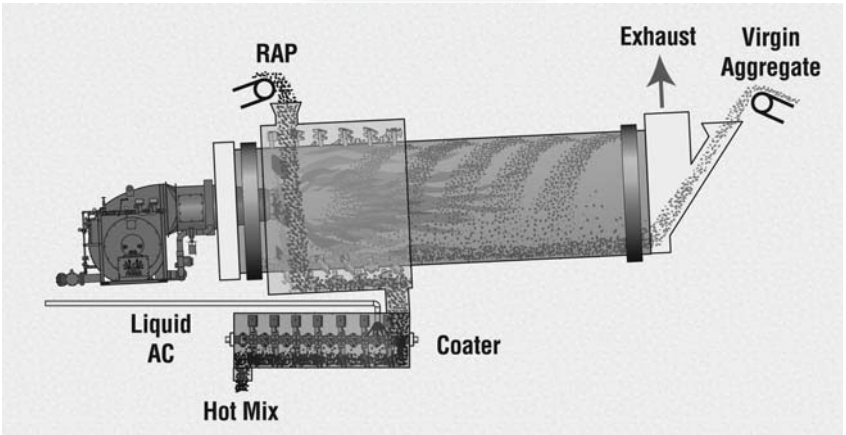
FIGURE 2B



Counterflow Drum Mixer

Figure courtesy of Astec, Inc.

FIGURE 2C



Double RAP Dryer with Coater

Figure courtesy of Astec, Inc.

RAP, generated from a process called ***Cold Planing,*** is normally hauled to a hot mix recycling plant for processing and future incorporation into a recycled mix. RAP also can be used as base aggregate, ditch lining, or as a surfacing for untreated gravel roads or parking areas.

Cold Planing removes an existing pavement to some desired depth, longitudinal profile, and cross-slope using powerful cold planers or milling machines. These machines (see Figure 3) are equipped with a large diameter rotary cutting drum that contains replaceable tungsten carbide teeth capable of grinding off the existing pavement. The textured pavement created from the milling operation provides a high skid resistant surface (see Figure 4) that can be driven on immediately, or subsequently can be overlaid with a new or recycled asphalt mix.

Milling and adding a new pavement is often referred to as a "mill and fill" process. This process eliminates the need to raise shoulders and guardrails because the height of the resulting pavement has not changed (see Figure 5). Bridge clearances and weight limits do not need to be changed when you mill off an old pavement and replace it with an equal thickness of new or recycled mix. The elevation of existing utilities also can remain unchanged when the "mill and fill" process is used. Milling operations can improve drainage patterns or grades of the pavement as well.

Hot In-Place Recycling consists of heating, scarifying, mixing, placing and compacting the upper layer of an existing asphalt pavement on site. Virgin aggregate, new asphalt binder, recycling agents, and/or new hot mix asphalt may be added as needed. Normally, 70 to 100 percent of the material in a mix which has been recycled in-place comes from the existing pavement. This approach requires several pieces of equipment such as pre-heaters, heaters, scarifiers, mixers, pavers, and rollers. The combined equipment is often referred to as a "train". Treatment depths range from ¾ to 3 inches depending on the Hot In-Place Recycling process used. The most common Hot In-Place Recycling processes are Surface Recycling, Remixing, and Repaving.

Surface Recycling involves heating and scarifying a thin surface of the existing pavement. After scarifying the surface, a recycling agent may be added and the loose material is mixed, placed, and compacted. Treatment depths are normally ¾ to 1½ inches. No new asphalt mix or virgin aggregate is added in the Surface Recycling process. However, the surface recycled mix is generally overlaid with a chip seal or hot mix asphalt.

FIGURE 3

Typical Front Loading Milling Machine

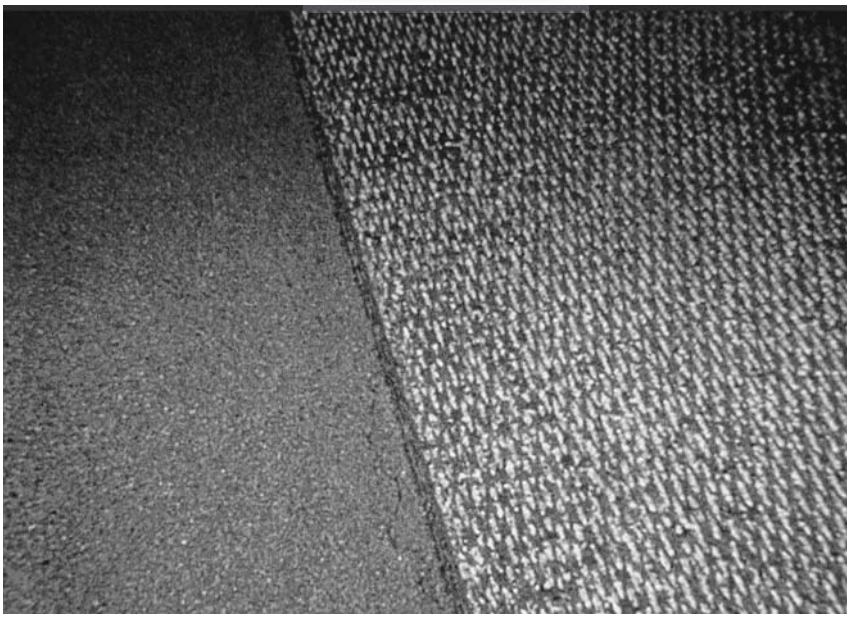
Photo courtesy of Astec, Inc.

Remixing is used when the properties of the existing pavement need to be improved by the addition of new materials. In the Remixing process, virgin aggregate, new asphalt binder, recycling agent, and/or new asphalt mix are added to the material that is recovered from the heated and scarified pavement surface. The composite recycled mix is then placed in one layer using the equipment train (see Figure 6). The recycled mix from this process can be used as a wearing surface or it can be overlaid with a chip seal or new asphalt mix. Treatment depths are normally 1 to 3 inches depending on whether the Remixing process is done in a single or multiple stage operation. Since new materials are added in this process, the overall pavement thickness will increase slightly, generally 30 percent or less.

The Repaving process essentially combines the Surface Recycling or Remixing process with the addition of a new hot mix asphalt overlay (see Figure 7). The Surface Recycled or Remixed layer and the new hot mix overlay are compacted together. The recycled mix acts as a leveling course and the new hot mix serves as the wearing course over the recycled pavement. Since the asphalt overlay can be anywhere between ¾ and 3 inches thick, the overall pavement thickness is increased significantly.

Cold Mix Recycling is a method of recycling where RAP, new aggregate (if needed), and emulsified asphalt or an emulsified recycling agent are combined without the need for heat in a centrally located cold mix plant. Since the components of a cold mix plant are fairly portable, it can be assembled in satellite locations close to a project site. Cold recycled mix is hauled to the job site with conventional dump trucks or belly dump trucks. Placement and compaction of

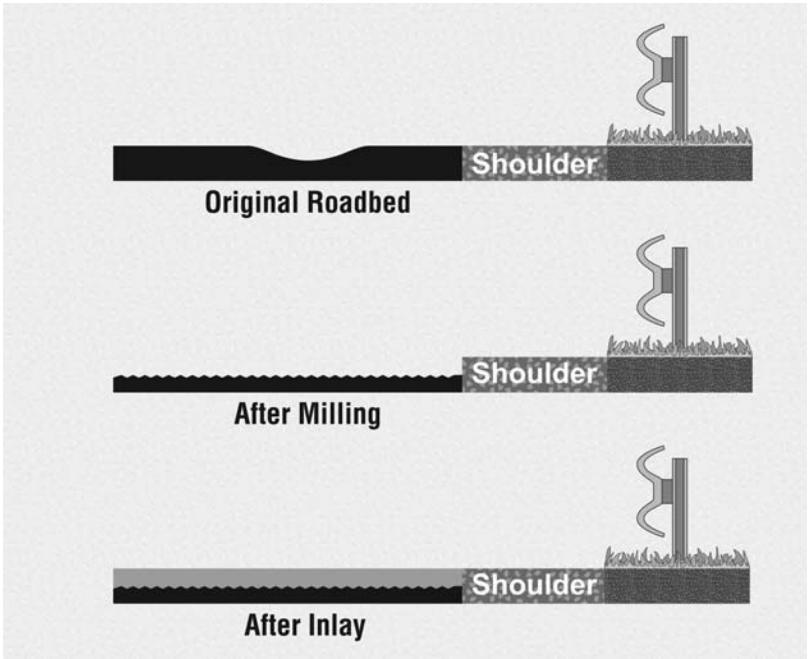
FIGURE 4



Milled Pavement Surface Improves Friction

Photo courtesy of Astec, Inc.

FIGURE 5



Mill and Fill Process Eliminates Need for Shoulder and Guardrail Changes

Image courtesy of Astec, Inc.

cold recycled mixes are done with the same conventional pavers and rollers used for hot mix asphalt construction. Cold recycled mixes are normally overlaid with a hot mix asphalt or chip seal depending on the anticipated traffic level for the finished pavement.

Inadequate curing of cold recycled mixes can cause construction delays. Curing depends on several factors including environmental conditions, moisture in the mix, compaction level and voids content of the mix, and drainage of underlying layers. The addition of lime or cement can help accelerate the curing process[9].

Cold In-Place Recycling is done on site and generally uses 100 percent of RAP generated from the existing pavement. Treatment depths are normally 2 to 4 inches when conventional emulsified asphalts or emulsified recycling agents are used. However, depths of 5 to 6 inches can be realized when additives such as lime, cement, kiln dust, or fly ash are incorporated to improve the early strength and moisture resistance of the recycled mix.

Cold In-Place Recycling trains can range from single unit to multi-unit operations. A multi-unit train normally contains a milling machine, a screening and crushing unit, and a pugmill mixer (see Figure 8). The recycled mix is deposited in a windrow and subsequently placed with a conventional hot mix asphalt paving machine and compacted with large pneumatic-tired rollers and high energy vibratory rollers.

Full Depth Reclamation is a method of recycling where a predetermined amount of the underlying base or subbase material is blended with the entire thickness of the distressed asphalt pavement to produce an upgraded, uniform base material. Treatment depths can vary from 4 to 12 inches depending on the thickness of the existing pavement layers.

FIGURE 6

Hot In-Place Remixing Train

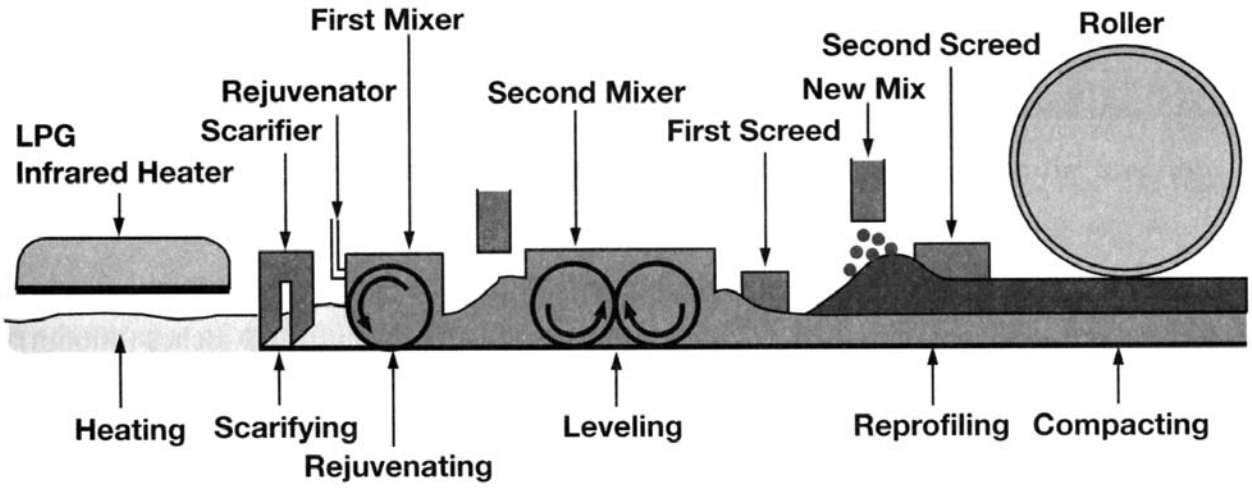
Photo courtesy of ARRA

Full Depth Reclamation is accomplished with reclaiming machines (see Figure 9). These reclaimers, which are essentially gigantic rototillers, are equipped with a pulverizing/mixing drum that rotates in an "up cut" direction (see Figure 10). Additives such as calcium chloride, lime, cement, fly ash, emulsified asphalt, or foamed asphalt are introduced to stabilize the blended material. The foamed asphalt stabilization process is described in more detail in another Tech Topic[10] available at *www.techtransfer.berkeley.edu/techtopics.* The time required for curing the stabilized material depends on the stabilizing additive used. Once cured, the reclaimed and compacted base material is normally overlaid with hot mix asphalt or some type of surface treatment.

Materials Evaluation

One of the key elements to a successful recycling project is proper evaluation and characterization of the materials involved. The amount of sampling and type of testing depends, in large part, on the recycling method selected. The process is fairly straightforward for Hot Mix Recycling where 15% or less RAP is used. The material from an existing pavement is typically milled and brought to a hot mix asphalt facility where it is crushed, screened, and stockpiled. The contractor then monitors the quality of the RAP to ensure uniformity through gradation and binder testing. Hot Mix Recycling that involves the use of 15-25% RAP will likely require an adjustment to the virgin asphalt selected (use of a softer grade). For higher than 25% RAP mixes, a more comprehensive processing, monitoring, and testing program for the RAP and the finished recycled mix is needed.

FIGURE 7



Hot In-Place Repaving Process and Equipment

Figure courtesy of ARRA

FIGURE 8

Multi-unit Cold In-Place Recycling Train

Photo courtesy of ARRA

In-place recycling requires field sampling and testing of the existing pavement. Field sampling is normally done by coring (generally 6-inch diameter cores). Dry coring with compressed air or nitrogen is preferred over wet coring since an accurate determination of moisture content is so critical for Hot In-Place Recycling and Cold Recycling processes. The number of field sampling locations can vary from 3 to 5 for smaller, uniform areas to 20 or more for larger, less uniform areas. The number of cores collected at each location depends on the amount of laboratory testing needed and the type of mix design testing required. The core samples should be examined for different pavement layers, previous surface treatments, interlayers, paving fabrics, specialty mixes, and evidence of stripping, disintegration, or moisture retention.

Representative samples should be tested for:

- ➜ moisture content
- ➜ gradation of the RAP
- ➜ asphalt binder content
- ➜ recovered asphalt binder properties
- ➜ aggregate properties (i.e., gradation, angularity)
- ➜ air void and density properties of the existing mix

Where Full Depth Reclamation is being considered, the base and subbase materials also need to be sampled and tested for:

- ➜ moisture content
- ➜ gradation and angularity
- ➜ Plasticity Index
- ➜ sand equivalency

The information obtained from a materials evaluation is used to help select the type and amount of recycling additive to use as well as to determine the need for additional aggregate to address any deficiencies in the existing pavement structure.

Mix Design Considerations

The complexity of a mix design process varies with the level and type of recycling selected. Hot Mix Recycling where 15% or less RAP is blended with new aggregate and virgin asphalt requires little change from the mix design procedure used on the virgin mix because the added RAP is not expected to significantly alter the properties of the final mix. However, for higher RAP contents (>25%), a more comprehensive mix design process is needed. Blend charts need to be developed using the asphalt recovered from RAP and virgin asphalt or recycling agent to determine the percentage of RAP that provides the desired binder and mix properties in the final recycled pavement.

The mix design process for Hot In-Place Recycling is, in many ways, similar to that used for high content RAP Hot Mix Recycling. Hot In-Place Recycling generally involves the use of 70-100% RAP. A simplified flow chart (see Figure 11) captures the key steps in a Hot In-Place Recycling mix design process. The binder properties of the asphalt recovered from RAP identified in this chart are penetration and viscosity. However, Superpave performance graded (PG) binder properties can also be measured and used in blend charts to determine the desired final asphalt grade in the recycled mix. A more comprehensive mix design flow chart for Hot In-Place Recycling is included on page 71 of the ARRA Basic Recycling Manual[4].

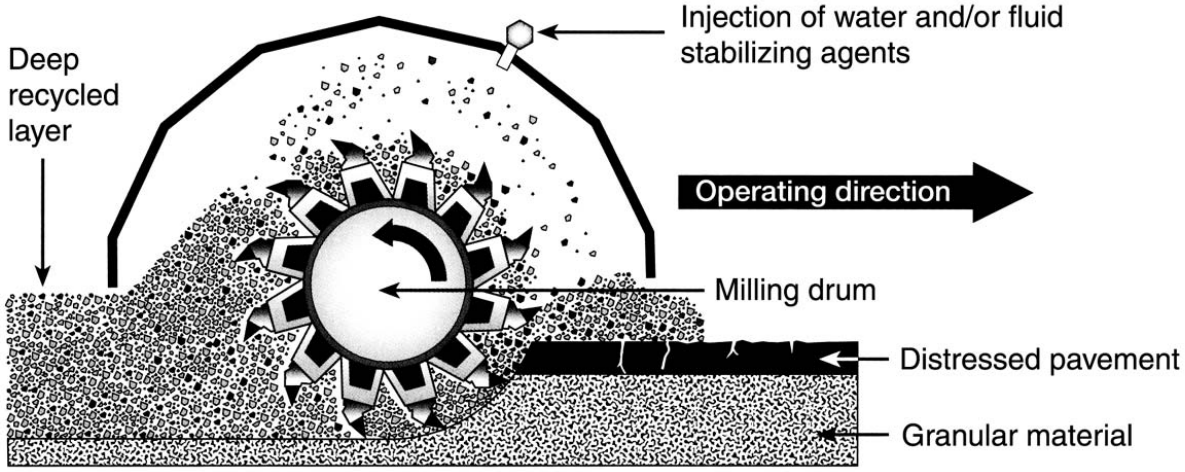
Cold Recycling (central plant or in-place) involves the use of emulsified asphalts, emulsified recycling agents, foamed asphalt, or chemical additives. The extent to which the aged asphalt binder is softened with these recycling additives is difficult to determine. Theories range from no softening (RAP acts as black aggregate) to complete restoration of the asphalt binder to its original consistency. Mix tests such as stability, resilient modulus (stiffness),

FIGURE 9

Reclaimer Used in Full Depth Reclamation

Photo courtesy of ARRA

FIGURE 10



Full Depth Reclamation Process

Figure courtesy of ARRA

and moisture sensitivity are often included in a mix design process for Cold Recycling. Testing also includes short-term and long-term curing considerations. A simplified mix design flow chart for Cold Recycling is included in Figure 12. More detailed information can be found in Asphalt Institute publications on Cold Mix and Cold Mix Recycling[11,12].

Structural Design Considerations

Structural design considerations are also important in recycling projects. Recycling and reclaiming processes can be used to correct structural deficiencies in the existing pavement and to address future traffic needs. Knowledge of the strength properties of the various pavement layers allows the designer to use mechanistic-empirical analysis to determine the required overall pavement structure. The load carrying capacity of the existing subgrade can be estimated from dynamic cone penetrometer or falling weight deflectometer measurements. The strength of the treated layers, including the recycled or reclaimed section, can be determined from stability, resilient modulus, and moisture sensitivity tests.

Quality Control/Quality Assurance

As with new pavement construction, an effective quality control/quality assurance (QC/QA) plan is essential to the success of a recycling project. QC/QA procedures, inspections, and specifications for Hot Mix Recycling are often similar to those used for new hot mix asphalt pavements, but with the added use of controls on the RAP material and the virgin asphalt binder selected based on RAP content. Inspection and QC/QA plans for Hot In-Place Recycling depend on the type of equipment being used on a particular project. Often a project will have two QC/QA components: one for the Hot In-Place Recycling portion and another for the hot mix asphalt overlay portion of the job. Some of the areas of concern for a contractor in a Hot In-Place Recycling QC plan include heating of the existing pavement, treatment depth, recycling agent addition, new material addition, placement, and compaction of the recycled mix. An effective QC/QA plan for Cold Recycling needs to be flexible enough to recognize that changes in moisture content, amounts of recycling agent, and/or rolling patterns are often necessary to obtain optimum product performance.

Development of workable QC/QA plans and specifications are often best accomplished through a joint effort between industry and agency personnel knowledgeable in the recycling process. For example, Caltrans and industry have worked together to

produce laboratory test procedures and guide specifications for both hot and cold recycling processes. Laboratory procedures can be viewed at *www.dot.ca.gov/hq/esc/Translab/fpm.htm.* Information on construction specifications for Cold In-Place and Hot In-Place Recycling can be obtained from Hamid Moussavi of Caltrans *(hamid_moussavi@dot.ca.gov*).

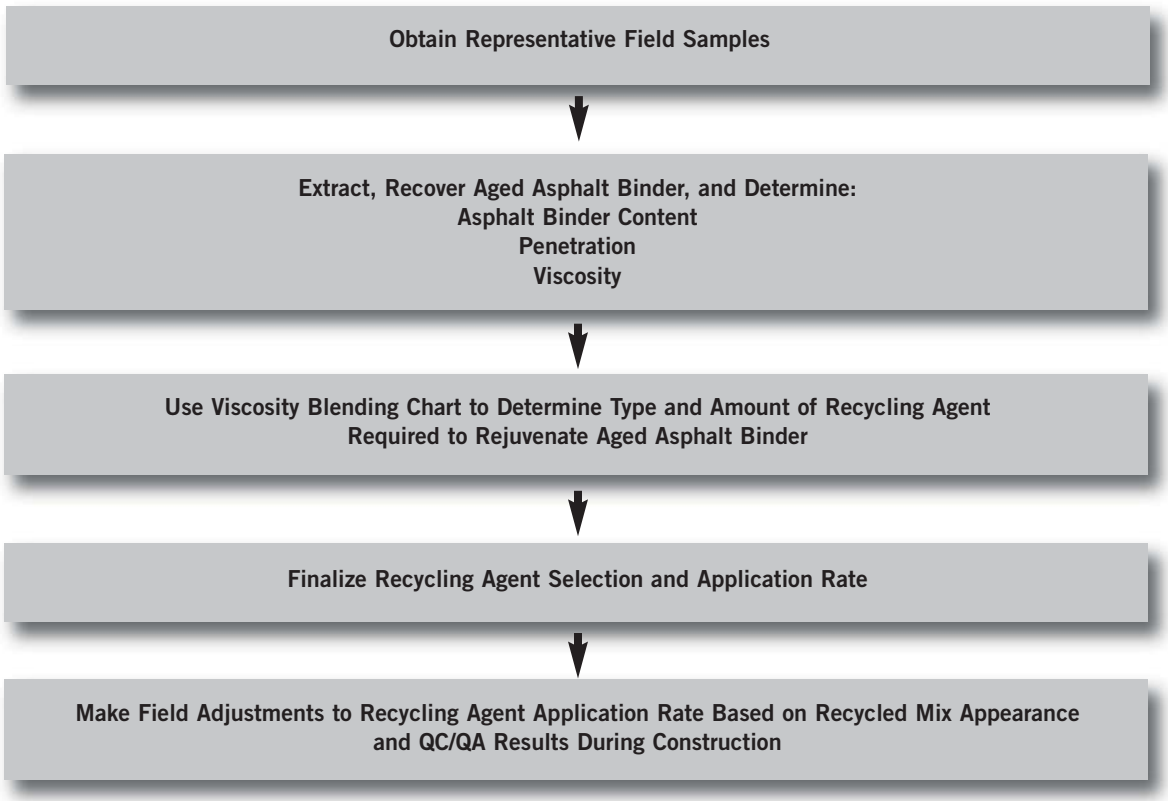
Strategy Selection

Each of the asphalt recycling processes discussed in this article has advantages and disadvantages. Selection of an appropriate recycling strategy is influenced by many factors including geometric considerations, environmental issues, materials and equipment availability, available funds, and past experiences. A "mill and fill" strategy may be the best choice for municipalities that need to maintain curb heights, existing drainage facilities, height clearances under overpasses, or weight limits on bridges. RAP has been used successfully in dense graded mixes. However, there are some concerns about using RAP in Open Graded Friction Courses (OGFC) and Rubber Asphalt Concrete (RAC) mixes. Caltrans does not permit the use of RAP in these mixes at this time.

Hot In-Place Recycling may be a better choice for sites where relatively long stretches of highway that can handle a large recycling train call for a rejuvenated hot mix asphalt pavement structure. Hot In-Place Recycling is not a good choice for recycling rubber modified asphalt pavements, because the heating process can produce a soft, sticky mix that can foul equipment subsequently used in the recycling train.

Cold Mix Recycling may be a more economical choice for secondary roads or remote locations, where traffic delays or diversions caused by slow curing conditions are less critical. When necessary, curing times can be reduced with the addition of small amounts of cement or lime to emulsified asphalts, or by the use of a more rapid set recycling alternative such as foamed asphalt.

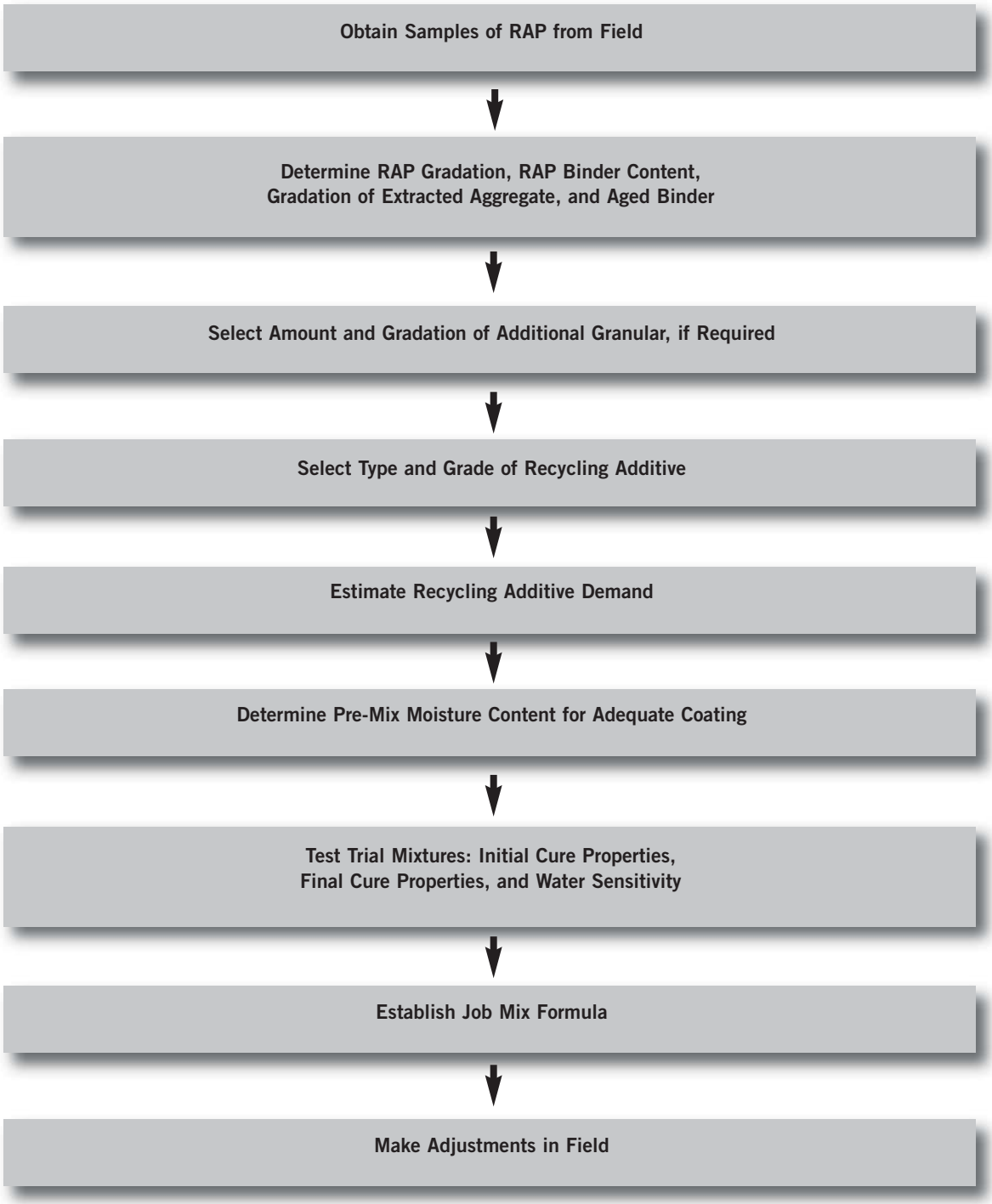
FIGURE 11



Hot Recycling Mix Design Flow Chart

Figure courtesy of ARRA

FIGURE 12



Cold Recycling Mix Design Flow Chart

Figure courtesy of ARRA

Most suppliers and contractors are very knowledgeable about the recycling options available and many can provide technical expertise directly or through paving associations to help an agency make informed choices. The Asphalt Pavement Association of California (*www.apaca.org*), headquartered in southern California, and the California Asphalt Pavement Association (*www.californiapavements.org*), whose office is located in northern California, are two sources for such information. Guidance on recycling processes can also be obtained from publications of industry groups, such as the Asphalt Recycling and Reclaiming Association (*www.arra.org*), the National Asphalt Pavement Association (*www.hotmix.org*), and the Asphalt Institute (*www.asphaltinstitute.org*).

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Figures and Photos

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