RECYCLING AND RECLAMATION ALTERNATIVES

RECYCLING ALTERNATIVES

COLD IN-PLACE RECYCLING

GENERAL INFORMATION

Generic Name(s): Cold In-Place Recycling (CIR)

Trade Names: N/A

Product Description: In-Place Recycling is an in situ process used to recycle 100% of an existing asphalt concrete pavement to construct a new asphalt concrete layer. Cold In-Place Recycling (CIR) is the rehabilitation of asphalt pavements without the application of heat during the recycling process.

In the CIR process, the existing asphalt is cold milled, mixed with about 1.5 to 2.0 percent of emulsified asphalt, and then placed on the road and compacted. The CIR material requires about 1 week of curing. The depth of treatment is typically 50 to 100 mm (2 to 4 in.) but 125 to 150 mm (5 to 6 in.) is also possible. Chemical additives (i.e., lime, cement, fly ash, etc.) are sometimes used to decrease the initial cure time (i.e. promote a more rapid strength gain) and also increase the ultimate strength of the material. New aggregate can also be added to the CIR, not exceeding 25% by weight of RAP, to improve the characteristics of the mix or to address a prior flushing problem.

CIR is commonly overlaid with HACP; however, on low volume roads, slurry seals, chip seals, or other surface treatments are used.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Asphalt Recycling & Reclaiming Association (ARRA), #3 Church Circle, PMB 250, Annapolis, MD 21401, (410) 267-0023, www.arra.org.

APPLICATION

Typical Use: Binder or base course with HACP or thin cold surfacing.

Traffic Range: Very Low to Medium. CIR use on higher volume roads typically requires thick HACP overlays.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: Constructability can be limited on steep grades or tightly curved roads due to the physical size of the equipment and process.

Soil Type: N/A

Other: As CIR depth is limited, it is not suitable for fixing problems with lower asphalt courses or granular base/ subbase. Pavements with major or extensive structural deficiencies (severe alligator cracking and severe structural rutting) are not good candidates for CIR.

Other Comments: Detailed pavement evaluation is required before designing the CIR pavement rehabilitation. The evaluation should include visual condition survey and evaluation of pavement structural condition, using pavement coring or the Falling Weight Deflectometer (FWD). Pavements exhibiting minor distresses (i.e. cracking, minor rutting) are excellent candidates for CIR.

When recycling material in-place, the depth of milling should be carefully examined to make sure that the underlying granular material is not introduced into the mix. Unless the base material is sound and very stable, the depth of milling is adjusted so that about 25 to 40 mm (1 to 1.6 in.) of the existing asphalt pavement is left in place; this will prevent the contamination of the recycled material with the granular base and will provide structural support for the CIR train during recycling.

The pavement to be CIR treated should be relatively homogenous. If the pavement structure or surface type within the project length changes, new mix design(s) may be required.

As the CIR equipment is relatively wide and long, short road sections particularly in urban setting are not suitable for CIR treatment, or may require special CIR equipment

DESIGN

SLC: 0.28 to 0.35.

Other Design Values: None.

Base/Subbase Requirements: Only the upper part of existing asphalt pavement is treated in the CIR process. Aggregate base and subbase layers are typically not included in the CIR process.

Other Comments: Asphalt pavements in poor structural condition are not considered to be suitable candidates for CIR treatment. If the pavement exhibits localized structural failures, full depth repairs including granular base and subbase may be required, as well as providing efficient surface and subsurface drainage. One of the major advantages of CIR is the mitigation of reflective cracking; in order to achieve this, at least 70 percent of the existing asphalt pavement thickness needs to be treated.

CONSTRUCTION

Availability of Experienced Personnel: Successful CIR processing requires experienced personnel. Experienced CIR contractors are, in general, regionally available in the United States.

Materials: New aggregates, emulsified asphalt, recycling agents and chemical additives such as portland cement or lime are added on an as-required basis. Chemical additives can be used to improve the strength of the material and decrease the initial cure time. Cationic and anionic mixing grade emulsions, both medium setting and slow setting, and high float emulsions, with and without modifiers are used in the CIR process.

Equipment: The CIR process uses a number of pieces of equipment including tanker trucks, milling machines, crushing and screening units, mixers, pavers and rollers. Single, two-unit and multi-unit trains are used in the CIR process. With the single unit train, the milling machine cutting head removes the pavement to the required depth and cross-slope, sizes the RAP and blends the recycling additive with the RAP. However, it does not contain screening and crushing units, making control of the maximum particle size more difficult.

Two-unit trains incorporate pugmill mix-pavers (cold mix pavers) as an integral part of the train. Multi-unit trailers include a trailer mounted screening and crushing unit and a trailer mounted pugmill mixer.

Equipment is available in urban areas, but availability may be limited in remote areas.

Cold In-Place Recycling Process: CIR is an in situ process. In the CIR process, a portion of the existing pavement is milled typically to a depth of 2 to 4 inches (50 to 100 mm). The reclaimed material is thoroughly mixed with emulsified asphalt and recycling agent to restore the properties of the asphalt binder in the mix. In the modified CIR process, new aggregates are also added. The resulting mixture is then placed back on the pavement as the base/binder course, with new wearing course (e.g., asphalt concrete, chip seal, slurry seal, etc.) placed later. Densification of the CIR mixes typically requires more compactive effort than conventional HACP and large pneumatic-tired rollers and vibratory steel drum rollers are used. Well compacted CIR mixes could have 9 to 14 percent Voids in Total Mix (VTM). Rolling with a steel roller several days after initial compaction (re-rolling) is used to remove minor consolidation in the wheel paths. The compacted CIR layers must be cured for a period of about 1 to 2 weeks of good weather before the wearing course is placed.

Weather Restrictions: CIR should not be performed at temperatures below 10 °C (50 °F) or when it is raining. It takes 1 to 2 weeks of good weather for the CIR material to cure.

Construction Rate: Modern CIR multi-unit trains can produce up to 3.2 lane km (2 lane miles) per day.

Lane Closure Requirements: The roadway lane(s) being constructed are closed during construction, so adequate traffic control is needed. The CIR surface can be opened to traffic during the curing period but heavy traffic should be avoided. When the CIR is cured, the roadway lane(s) must be closed for the surface course application (surface treatment or HACP overlay).

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: CIR is a proven recycling technology. Research, design and construction information, and project experience is available. Performance depends on proper pavement evaluation, mix design and quality of construction.

Life Expectancy: CIR with surface treatment generally lasts from 6 and 8 years. HACP overlays extend the CIR life expectancy to 12 to 20 years.

Ride Quality: CIR provides good ride quality after construction depending on the type of wearing course used. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Cracking, rutting, raveling.

Preservation Needs: No preventative maintenance is typically required because CIR is not commonly used as a surfacing.

SAFETY

Hazards: None.

Skid Resistance: N/A; CIR is not normally used as a surfacing.

Road Striping Possible?: N/A; not used as a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Emulsified asphalt is an asphalt product produced by distillation of crude oil. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: In the typical CIR process no material hauling is required (in situ process). In the modified CIR process, new aggregate must be hauled.

Potential Short-Term Construction Impacts: A certain amount of noise is associated with the CIR construction process. Construction processes may impact vegetation adjacent to the roadway.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: CIR is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by CIR present in a roadway.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: CIR pavement can be fully recycled as a pavement construction material.

Other Environmental Considerations: CIR's characteristic black surface will absorb heat from sunlight; since it is an in situ process there is little opportunity to modify its appearance. For CIR, tire/road noise is typically similar to HACP or surface treated pavement, depending on the type of wearing course used.

Environmental Benefits: As CIR does not require pre-heating; CIP results in total energy savings of 40% to 50% compared to conventional HACP.

AESTHETICS

Appearance: Immediately after placement, CIR is generally black with a smooth surface.

Appearance Degradation Over Time: Over time, the layer(s) overlaying CIR can change color to a wide range of gray-blacks and occasionally has a brown or red sheen, depending on the predominant aggregate color. With maintenance activities, such as crack sealing and patching, the surface appearance deteriorates further. Where special mixes are used, the future availability of similar mixes should be assured for maintenance purposes to lessen the aesthetic degradation.

COST

Supply Price: N/A

Supply+Install Price: \$4.20 to \$4.80/m^2 (\$3.50 to \$4.00/yd^2) for 75 mm (3 in.) recycling depth.

EXAMPLE PROJECTS

Mooney Road, Lassen National Forest, Lassen County, CA.
Grand Tetons National Park, WY.
Badlands National Park, SD.

SELECT RESOURCES

Asphalt Recycling & Reclaiming Association (ARRA), (410) 267-0023, www.arra.org
ARRA (2001). *Basic Asphalt Recycling Manual*, Publication No. NHI01-022, American Recycling and Reclaiming Association, 270 pp.

HOT IN-PLACE RECYCLING

GENERAL INFORMATION

Generic Name(s): Hot In-Place Recycling (HIR)

Trade Names: N/A

Product Description: The Hot In-Place Recycling (HIR) process consists of (1) heating and softening the existing asphalt pavement so it can be scarified or hot rotary milled to the specified depth, (2) mixing the loosened asphalt pavement with a recycling (rejuvenating) agent and possibly additional virgin asphalt and (3) placing and compacting the mixture with conventional hot mix asphalt paving equipment. This process is called heater-scarification (or reshaping). In the HIR repaving process, heater-scarification is simultaneously combined with an overlay of HACP. When additional materials are needed to recycle the pavement, such as mineral aggregate or virgin hot mix asphalt concrete, the remixing process is used. Typical treatments depths range from 19 to 50 mm (0.75 to 2 in.). HIR is usually surfaced with a hot mix asphalt concrete overlay or chip seal, but is sometimes used as a surface course on low volume roads.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Asphalt Recycling & Reclaiming Association (ARRA), #3 Church Circle, PMB 250, Annapolis, MD 21401 www.arra.org.

APPLICATION

Typical Use: Road surfacing, binder course.

Traffic Range: Very Low to High. Heater-scarification process should be used only for low volume traffic. Remixing and repaving processes can be used on high traffic volume roads.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: Constructability can be limited on steep grades or tightly curved roads due to the physical size of the equipment and process.

Soil Type: N/A

Other: As HIR depth is limited, it is not suitable for fixing material or performance problems with lower asphalt courses or with the granular base. Pavements with major or extensive structural failures (severe alligator cracking and severe structural rutting) are not good candidates for HIR. As the HIR equipment is relatively wide and long, short road sections particularly in urban settings are not suitable for HIR treatment.

Other Comments: The typical HIR process requires a minimum of 75 mm (3 in.) of existing asphalt pavement. Detailed pavement evaluation is required before designing the HIR pavement rehabilitation. The evaluation should include visual condition survey and evaluation of pavement structural condition, using the Falling Weight Deflectometer (FWD) for instance.

If required strengthening is less than 19 mm (0.75 in.) of HACP, the pavement can be treated with remixing or repaving. If required strengthening is greater than 19 mm (0.75 in.) of HACP, but less than 50 mm (2 in.), the repaving process can be used. HIR is not suitable if required strengthening is greater than 50 mm (2 in.) of HACP. The pavement to be HIR treated should be relatively homogenous. If surface treatments, crack sealants, etc. are present, they should be removed. Large patches may require their own specific mix designs.

DESIGN

SLC: 0.30 to 0.35.

Other Design Values: None.

Base/Subbase Requirements: Only the upper part of existing asphalt pavement is treated in the HIR process. Base and subbase layers are not included in the HIR process. Existing base/subbase support must provide adequate structural support.

Other Comments: If the pavement exhibits severe or extensive structural failures, full depth repairs including granular base and subbase may be required, as well as providing efficient surface and subsurface drainage.

CONSTRUCTION

Availability of Experienced Personnel: Successful HIR process requires experienced personnel. Experienced HIR contractors are, in general, regionally available in the United States.

Materials: New aggregates, new asphalt binder, recycling/rejuvenating agents and/or new hot mix asphalt concrete can be added on an as-required basis. Typically, new aggregates or HMA additions are limited to 30 percent by mass of HIR mix.

Equipment: The HIR process uses a number of pieces of equipment, including pre-heaters, heaters, heater-scarifiers, mixers, pavers and rollers. The HIR equipment, called a recycling "train", has a length of approximately 45 m (150 ft).

Equipment is available in urban areas, but availability may be limited in remote areas. Mobilization costs may make small projects uneconomical.

Hot In-Place Recycling Process: There are three sub-categories within HIR: heater-scarification (also called surface recycling); remixing; and repaving.

Heater-scarification is the process in which softening of the asphalt pavement surface is achieved with heat from a series of pre-heating and heating units. The heated and softened surface layer is then scarified to a predetermined depth, a recycling (rejuvenating) agent is added, the loose recycled material is thoroughly mixed, and then placed with a standard paver screed. The depth of treatment typically ranges from 12 to 20 mm (0.5 to 0.75 in.), although treatments as deep as 50 mm (2 in.) have been used. No new aggregate or HACP are added in the heater-scarification process. Compaction of the recycled mix is with conventional rollers. A chip seal or HACP overlay is generally placed in a subsequent operation.

Remixing is the HIR process in which the existing asphalt pavement is heated, softened, scarified, and new aggregate, new asphalt binder, recycling agent, and/or new HACP is added and the resultant blend is thoroughly mixed. The recycled mix is then placed and compacted in one layer. The remixing process is used when the existing asphalt pavement requires significant modification. The recycled mix is usually left as the wearing course, although chip seal or HACP overlay are sometimes placed as a separate operation. Treatment depth is 25 to 50 mm (1 to 2 in.).

Repaving combines the heater-scarification or remixing process with the placement of an 'integral' overlay of new HACP. The recycled mix and new HACP overlay are compacted together. The thickness of the HACP wearing course ranges from 20 to 75 mm (0.75 to 3 in.).

Weather Restrictions: HIR should not be performed at temperatures below 10 °C (50 °F) or when it is raining.

Construction Rate: For heater-scarification HIR process, construction rates depend on ambient temperature, characteristics of the asphalt pavement being treated, moisture content of the pavement and the heat output of the equipment. Construction rates range from 1.5 to 15 m/min. (5 to 50 ft/min).

In the remixing process, construction rates depend on the same variables as for the heater-scarification plus the amount of admixture being added and the remixing treatment depth. Construction rates range from 1.5 to 10 m/min. (5 to 35 ft/min).

Lane Closure Requirements: The roadway lane being constructed is closed during construction, so adequate traffic control is needed. The HIR surface can be opened to traffic as soon as the HIR has cooled and construction equipment is cleared from the roadway.

Other Comments: It is critical that the rejuvenating agent is applied uniformly and the depth of HIR treatment is consistent during the HIR process.

SERVICEABILITY

Reliability and Performance History: HIR is considered to be a proven recycling technology. Research, design and construction information, and project experience is available. Performance depends on proper pavement evaluation, mix design and quality of construction.

Life Expectancy: Life expectancy varies depending on the type of HIR process, mix types, environmental conditions, traffic volumes and degree of routine maintenance. Typical serviceable lives are: heater-scarification process with no subsequent surface treatment - 2 to 4 years; heater scarification with surface treatment - 6 to 10 years; remixing - 7 to 14 years; and, remixing with subsequent HACP overlay - 6 to 15 years.

Ride Quality: HIR provides good to very good ride quality after construction, depending on the type of wearing course used. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Raveling, cracking, rutting. Cracks in the untreated part of the pavement will reflect through the recycled layer within 1 to 2 years in colder climates.

Preservation Needs: Preventative maintenance includes periodic crack sealing and localized patching every 7 to 9 years. Thin surface treatments can be applied to extend the serviceable life of HACP.

SAFETY

Hazards: Road splash/spray can reduce visibility during periods of higher traffic volume.

Skid Resistance: Provided high quality aggregates are used in the recycled mix or HACP overlay, HIR provides good to excellent skid resistance.

Road Striping Possible?: Yes.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Asphalt cement is an asphalt product produced by distillation of crude oil. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: In the heater-scarification process no material hauling is required. In the remixing and repaving processes, hot mix asphalt concrete must be hauled from a stationary asphalt plant unless a mobile asphalt plant is assembled. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: Significant heat is generated during the HIR process. “Flare-ups” can occur if excessive pre-heater temperatures are used, especially where there is existing crack sealant. Construction processes may impact vegetation adjacent to the roadway. HIR has the potential to create fugitive emissions in the form of blue or white smoke depending on the type of equipment, type of pavement material recycled and the ambient conditions, including temperature, wind velocity and direction. A certain amount of noise is associated with the process. Immediately prior to HIR, road utilities should be checked for the presence of any flammable vapors/gases and should be cleared by the Fire Marshal.

Some rejuvenating agents may be carcinogenic and their application during construction requires special care. A health and safety plan as well as a spill prevention and containment plan should be in place prior to handling carcinogenic rejuvenating agents to protect the health of personnel and the environment.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: HIR is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by HIR roadways.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: HIR can be fully recycled as a pavement construction material.

Other Environmental Considerations: HIR's characteristic black surface will absorb heat from sunlight. Since HIR is essentially an in situ processing, there is limited scope to modify the finished product appearance, except by the addition of a surface treatment. HIR does improve the appearance of an old, deteriorated asphalt surfaces. For HIR, tire/road noise is typically similar to a HACP or surface treated pavement, depending on the type of wearing course used.

AESTHETICS

Appearance: Immediately after placement, HIR is generally black with a very smooth surface.

Appearance Degradation Over Time: Over time, HIR can change color to a wide range of gray-blacks and occasionally has a brown or red sheen, depending on the predominant aggregate color. With maintenance activities, such as crack sealing and patching, the surface appearance deteriorates further. Where special mixes are used, the future availability of similar mixes should be assured for maintenance purposes to lessen the aesthetic degradation.

COST

Supply Price: N/A

Supply+Install Price: *Heater-scarification*: \$0.90 to \$1.60/m^2 (\$0.75 to \$1.35/yd^2).

Remixing: \$1.50 to \$2.40/m^2 (\$1.25 to \$2.00/yd^2).

Repaving: \$2.40 to \$3.90/m^2 (\$2.00 to \$3.25/yd^2).

EXAMPLE PROJECTS

Route 58, Lowell to Irasburg, VT.

SELECT RESOURCES

Asphalt Recycling & Reclaiming Association (ARRA), (410) 267-0023, www.arra.org
ARRA (2001). *Basic Asphalt Recycling Manual*, Publication No. NHI01-022, American Recycling and Reclaiming Association, 270 pp.

PORTLAND CEMENT CONCRETE PAVEMENT (PCCP) RECYCLING AND REHABILITATION

GENERAL INFORMATION

Generic Name(s): Reclaimed Concrete Aggregate (RCA), Rubblized Concrete, Crack and Seat

Trade Names: N/A

Product Description: Reclaimed Concrete Aggregate (RCA) is a well graded high quality aggregate produced by crushing old PCC or PCCP. The RCA is generated through the demolition of existing PCCP, PCC curbs, sidewalks, and/or driveways. It can be used by itself as an unbound pavement base or subbase layer in a pavement structure or can be blended with virgin aggregate or RAP.

Rubblization is the process of fracturing concrete slabs in situ, usually by impact with a resonating beam; the fractured slabs are used to form a base layer for an asphalt concrete overlay. Resonant breakers typically operate at a high frequency (44 Hz) and low amplitude (12 mm [0.5 in.]). Ideally, the concrete is broken into 25 to 75 mm (1 to 3 in.) chunks at the top and into 75 to 150 mm (3 to 6 in.) chunks towards the bottom.

Crack and Seat is a process where PCCP slabs are broken in situ using guillotine hammers or multi-head breakers, into relatively large chunks (300 mm [12 in.]) and above. The broken concrete is then rolled to bed it into the underlying base so that it can form the base layer of a reconstructed pavement.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors who can supply RCA can be obtained from: National Stone, Sand, and Gravel Association (NSSGA), 1605 King Street, Alexandria, VA 22314, (800) 342-1415, www.nssga.org.

Information on contractors who perform rubblization can be obtained from Resonant Machines Inc. Tulsa, OK, www.resonantmachines.com.

APPLICATION

Typical Use: Base course. RCA is not recommended for unbound road surfacing due to surface dusting problems and the alkaline nature of water runoff.

Traffic Range: Very Low to High, depending on thickness of HACP added.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: Many agencies do not allow the use of RCA within 1 m (3 ft) of the water table because of its potential impact on water quality. Rubblizing has proved to be very effective even on very thick airfield pavements (over 330 mm [13 in.]). With the use of resonant breakers, the concrete slabs need to have adequate structural support to facilitate fracturing of the concrete.

Other Comments: Recycling of PCCP requires removal of steel reinforcing and mesh.

DESIGN

SLC: 0.14 for RCA; 0.14 to 0.25 for rubblized concrete.

Other Design Values: None.

Base/Subbase Requirements: The RCA, rubblized concrete, or crack and seat concrete forms the new base for the reconstructed road; any underlying old base or subbase materials can be treated as subbase in design.

Additional granular base may be needed in the case of rubblization and crack and seat.

Other Comments: RCA may become less permeable over time. Pavement designs incorporating rubblized concrete generally need the addition of edge drains.

CONSTRUCTION

Availability of Experienced Personnel: Contractors capable of producing and placing RCA are available throughout the United States. Rubblizing and crack and seat technology are limited to more specialized contractors with limited availability outside urban centers.

Materials: RCA consists of PCC derived from deteriorated rigid pavements or associated old concrete infrastructure.

Equipment: PCCP recycling requires several pieces of equipment, including combinations of a resonant pavement breaker, multi-head breaker, crushers; front end loaders; rear or bottom dump trucks for hauling material, water trucks, graders, and compactors or rollers. Availability of specialized breaker equipment may be limited in remote areas.

PCCP Recycling and Rehabilitation Process: RCA is produced through crushing and screening of concrete chunks derived from demolition. The process is similar to any aggregate production operation, although steel will need to be removed and caution needs to be exercised in avoiding the inclusion of lower quality materials, such as bricks, wood, and organics. The RCA is placed in a similar manner to other aggregate materials. RCA has higher water absorption properties than virgin aggregates and this may impact compaction characteristics and may require the addition of more water than for conventional aggregates.

Rubblization involves reducing an old PCCP to rubble or relatively small aggregate-sized particles. It is performed by dedicated equipment referred to as resonant breakers. The rubble is then used as an unbound base course to support a flexible pavement.

Crack and Seat is performed by repeated blows of a multi-head breaker or by drop weights or guillotine hammers. The hammers are dropped from variable heights between 0.3 and 1.5 m (1 to 5 ft) to create impact energies between 2,700 and 16, 300 N-m (2,000 to 12,000 ft-lb). The PCCP slabs are broken into pieces in the size range of 0.3 to 0.6 m^2 (1 to 2 ft^2). The pieces are then seated by 2 or 3 passes of a large rubber tired roller.

Weather Restrictions: Avoid construction during heavy rain or snow events and when the soil is frozen.

Construction Rate: RCA construction rates are in the range of 300 to 1,200 m^3/day (400 to 1,500 yd^3/day). Rubblization rates range from 5,000 to 8,400 m^2 /day (6,000 to 10,000 yd^2/day). Crack and seat rates are in the range of 10,000 to 15,000 m^2 /day (12,000 to 18,000 yd^2/day).

Lane Closure Requirements: The roadway lane being constructed is closed during construction, so adequate traffic control is needed. The RCA surface can generally be opened to temporary traffic as soon as construction is complete and construction equipment is cleared from the roadway. Rubblized surfaces could be used temporarily for slow moving traffic, but it is not recommended. Crack and seat surfaces are not suitable for temporary traffic unless additional granular is placed or the first lift of HACP is in place.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: RCA used as a replacement for conventional granular base or subbase is very effective. Rubblizing has been found to be more effective than crack and seat in minimizing reflection cracking. However, even with rubblizing, reflection cracking can possibly occur as a result of larger concrete chunks near the pavement edge or under existing reinforcing steel.

Life Expectancy: Life expectancy with the use of RCA for base or subbase layers would be similar to virgin aggregate. HACP or hot mix overlays above rubblized or crack and seat concrete should have life expectancies of 15 to 20 years.

Ride Quality: If overlaid with hot mix asphalt concrete, RCA, rubblized, and crack and seat concrete can provide very good ride quality after construction. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Rutting, cracking.

Preservation Needs: No preventative maintenance is typically required to the recycled concrete products because these layers are not used as a surfacing.

SAFETY

Hazards: None.

Skid Resistance: When used as a temporary road surfacing, RCA layers can provide adequate skid resistance.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Recycled and processed PCCP is constructed of coarse and fine aggregates, portland cement, water, and chemical admixtures. The aggregates in the mix are naturally occurring and are obtained through mining or dredging. Portland cement is manufactured from limestone through a very energy intensive process.

Delivery and Haul Requirements: RCA is produced at an aggregate plant and hauled to the site. The raw material is concrete chunks obtained from demolition sites or from old PCCP removal. Rubblizing and crack and seat are both in situ processes and no hauling is required.

Potential Short-Term Construction Impacts: Noise is associated with the operation of resonant breakers and even more so with the crack and seat process. This latter process may not be suitable in highly residential locations. Construction processes may impact vegetation adjacent to the roadway.

Potential Long-Term Environmental Impacts:

Leachate: The leachate from RCA has a number of potential concerns, including highly alkaline runoff, a potential to clog drainage systems (especially those consisting of geotextiles), and potential to cause corrosion of nearby metal pipes. The pH of the leachate is generally in the 11 to 12 range. RCA may also contain some contaminants depending on the source of the original PCCP. Rubblized and crack and seat concrete would not give rise to leachate.

Surface Runoff: None, when used as a base layer.

Erosion: None.

Water quality: RCA can potentially impact the pH of surrounding waters due to the high pH of the leachate.

Aquatic species: RCA impacts water quality and so may be detrimental to aquatic species.

Plant quality: RCA does not directly impact plant quality but the leachate can impinge on plant quality.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: RCA and rubblized PCCP can be fully recycled and reused as a pavement construction material. Crack and seat concrete would have limited ability for economic recycling.

Other Environmental Considerations: None.

AESTHETICS

Appearance: RCA, rubblized PCCP, and crack and seat PCCP are generally not left exposed. The appearance of RCA and rubblized concrete is similar to a light colored crushed aggregate. Crack and seat concrete has an appearance of embedded concrete chunks.

Appearance Degradation Over Time: N/A; RCA is not exposed as a surfacing.

COST

Supply Price: N/A

Supply+Install Price: RCA costs will be location specific but can range from \$15.00 to \$30.00/m^3 (\$12.50 to \$25.00/yd^3). The cost of rubblizing and crack and seat varies widely depending on location, and size of project.

EXAMPLE PROJECTS

East-West Tollway (I-88) Pavement Rehabilitation (Rubblization), DeKalb and Kane Counties, IL.
Wright-Patterson Air Force Base, Fairborn, OH (Rubblization).

SELECT RESOURCES

AASHTO, *Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course*, AASHTO Designation: M 319-02
FHWA, *User Guidelines for Waste and By-Product Materials in Pavement Construction*, USDOT, FHWA Pub No. FHWA-RD-97-148, 1997.

RECYCLED HACP

GENERAL INFORMATION

Generic Name(s): Recycled HACP, Recycled Hot Mix Asphalt, Recycled Hot Asphalt Concrete Pavement.

Trade Names: N/A

Product Description:

Recycled hot asphalt concrete pavement is HACP that contains a mixture of virgin asphalt binder and aggregate combined with cold milled HACP from old pavement structures. This cold milled product is generally referred to as Reclaimed Asphalt Product (RAP). Recycled HACP mixtures typically can contain up to 30% by mass of cold milled HACP (RAP), although higher amounts can be used depending on the proposed use. Surface course mixtures generally will use less or no recycled HACP, and binder courses will use more. The asphalt mix proportions need to be designed to suit the particular application.

HACP is a high quality pavement material that is hot mixed at a plant and then hot laid. It is the most common surfacing for paved roads in the U.S., accounting for more than 90% of paved roads.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: National Asphalt Pavement Association, 5100 Forbes Blvd., Lanham, MD 20706, (888) HOT-MIXX, www.hotmix.org.

APPLICATION

Typical Use: Road surfacing, binder course.

Traffic Range: Very Low to High.

Restrictions:

Traffic: A high stability mix should be used for high traffic volumes and for heavy industrial loading conditions (i.e. slow moving trucks, frequent braking, etc.)

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: None.

Other Comments: The grade of asphalt cement needs to be selected based on service temperature ranges, traffic volumes and amount of RAP to be added to the mixture. Traditionally, asphalt cement grades have been designated as penetration grade (60/70, 85/100, etc.) or by viscosity grades (AC-10, AC-20, AR-4000, etc.). Currently, asphalt cements are specified by Performance Grades (PG), such as PG 64-22, indicating the high and low temperature range in °C. With the use of modifiers, the serviceable temperature range is extended so rutting can be avoided at high temperatures and transverse cracking can be avoided at low temperatures. Typically the addition of up to 20% RAP will not change the grade of asphalt binder required for a mixture. When RAP contents exceed 20%, typically a softer grade of asphalt binder is used to offset the stiffer, oxidized asphalt binder present in the RAP.

For very low to low traffic applications, recycled HACP mixes should be designed so that compaction from traffic is not relied upon to help achieve the target mix air void content as is commonly done for high volume applications. Inadequately compacted recycled HACP will have a higher air void content, making it more permeable and susceptible to oxidation. When recycled HACP oxidizes, it becomes brittle, which leads to cracking. Modifiers can be used in the asphalt cement to improve ductility and reduce the effects of oxidation.

DESIGN
SLC: 0.35 to 0.40. **Other Design Values**: None. **Base/Subbase Requirements:** Recycled HACP is usually constructed over an aggregate base course, but may be placed directly over a prepared subgrade of native materials. The required recycled HACP thickness depends on the design traffic and the level of base/subbase support provided. Subgrade and base materials should be graded and compacted to provide a stable working surface prior to recycled HACP placement. A prime coat is sometimes used above the aggregate base prior to paving. Tack coats can be used to improve the bond between hot mix layers. **Other Comments:** As a general guideline, the minimum recycled HACP lift thickness should be three times the nominal maximum aggregate size.
CONSTRUCTION
Availability of Experienced Personnel: Most HACP paving contractors can also place recycled HACP, so experienced contractors are, in general, widely available. Availability may be limited for projects in remote areas. **Materials**: Recycled HACP is composed of a blend of coarse and fine aggregate and mineral filler with asphalt cement as a binder, combined with cold milled HACP from old pavement structures. Modified asphalt cement and/or additives can be used to enhance certain performance characteristics. **Equipment**: Equipment required for recycled HACP construction includes: haul vehicles, asphalt distributor (if prime or tack coats are applied), asphalt paver machine, and compaction equipment (static steel wheel roller, pneumatic tire roller, or vibratory roller). Where high a quality finish and smoothness are required, a material transfer vehicle (MTV) can be used to provide more uniform feed of hot mix to the paver. The use of an MTV also reduces the potential for mix segregation. Equipment is widely available in urban areas, but availability may be limited in remote areas. **Manufacturing/Mixing Process**: HACP is hot mixed at a stationary asphalt plant by mixing specified proportions of the heated material components together to form a uniform mixture. For recycled HACP, an additional step is added; the cold milled HACP is fed by a conveyor system into a hot mixing chamber. The RAP, which is essentially asphalt binder coated aggregate, is mixed together with the virgin aggregate in the hot mixing chamber to form a homogeneous mixture. HACP mixes are normally mixed at temperatures between 132 to 163 °C (270 to 325 °F). However, depending on the content of RAP to be added, the temperatures may need to be increased. After mixing, the product is placed in haul vehicles to be transported to the project site. The asphalt concrete mix must arrive on-site and be placed before it cools. When transported in insulated vehicles with a tarp cover, the asphalt mixture can remain at an adequate temperature for up to 2 or 3 hours. When the project site is far from an asphalt plant, a portable asphalt plant can be assembled near the project site. When selecting a site for a portable asphalt plant, impacts to the environment and local residents and businesses must be considered. **Placement Process**: Upon arrival at the site, the asphalt concrete mixture is transferred from the haul vehicles into the paver hopper, spread onto the prepared working surface by the paver, and leveled by a screed at the rear of the asphalt paver. The recycled HACP is then rolled with compaction equipment to achieve the required density. The compaction process should be completed before the asphalt binder stiffens to a point where additional compactive effort will damage the mat. Typically, this range is from 150 °C (300 °F) down to 85 °C (185 °F). This temperature range may not apply to modified binders. Experience has shown that the compaction process may continue to temperatures below 85 °C (185 °F) when modified binders have been used. The time available for compaction before the mix has cooled will depend on the mix temperature when it is placed, layer thickness, air temperature, and wind, but can range from several minutes to more than 30 minutes. **Weather Restrictions**: Do not place recycled HACP if it is raining or there is ponded water on the prepared paving surface or if the surface is frozen. The specified minimum air temperature for recycled HACP placement varies between different agencies, but is normally about 7 °C (45 °F).

Construction Rate: Recycled HACP placement rates are similar to those for HACP, and will depend on the speed that the asphalt concrete mixture is delivered, layer thickness, and paving width. Placement rates can be 0.2 m/sec (40 ft/min) or higher. Compactor speeds are normally limited to 4.8 km/hr (3 mph), so overall construction rates are often dictated by the number of compactors on site. Typical production rates are 900 to 4,500 Mg/day (1,000 to 5,000 tons/day).

Lane Closure Requirements: The roadway lane(s) being constructed are closed during construction, so adequate traffic control is needed. The recycled HACP surface can be opened to traffic as soon as it has cooled and construction equipment is cleared from the roadway. Road surface striping may be performed before or after the lane is opened.

Other Comments: None.

SERVICEABILITY

Reliability and Performance History: Recycled HACP is a very common roadway surfacing. With the increased use of cold milling / cold planing, paving contractors generate significant quantities of RAP. Since, in general, the RAP contains good quality aggregates and old asphalt binder, it is cost-effective to include it in HACP. Provided the percentage of RAP is kept below about 30%, it does not significantly impact the overall quality of the mix. With properly prepared mix designs, recycled HACP is found to perform as well as HACP. However, most agencies forbid or strictly limit the inclusion of RAP in premium wearing course mixes, because of the fact that it is a component of the mix that is not subject to strict quality control verification. Some agencies will only allow RAP that has been milled from their project site to be used, in an effort to control the quality of the RAP component. An extensive amount of research, design and construction information, and project experience is available.

Life Expectancy: Life expectancy varies depending on mix types, environmental conditions, traffic volumes, degree of routine maintenance and amount of RAP added to the mixture. Typical serviceable lives are similar to HACP and range from 15 to 20 years.

Ride Quality: Very good ride quality after construction. Ride quality deteriorates over the serviceable life.

Main Distress / Failure Modes: Cracking, rutting, raveling, loss of surface friction.

Preservation Needs: Preventative maintenance includes periodic crack sealing and localized patching every 7 to 9 years. Thin surface treatments can be applied to extend the serviceable life of recycled HACP.

SAFETY

Hazards: Road splash/spray can reduce visibility during periods of higher traffic volume.

Skid Resistance: Provided only RAP from known sources is used in the asphalt concrete mix, recycled HACP provides good to excellent skid resistance.

Road Striping Possible?: Yes.

Other Comments: Because recycled HACP provides a high-quality road surfacing, there is a tendency for higher road usage and speeding.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Asphalt cement is an asphalt product produced by distillation of crude oil. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: Recycled asphalt concrete must be hauled from a stationary asphalt plant unless a mobile asphalt plant is assembled, in which case the cold milled HACP and virgin mix materials must be hauled to the mobile plant. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: Significant heat is generated during the mixing and placement process. Construction processes may impact vegetation adjacent to the roadway.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Recycled HACP is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by recycled HACP roadways.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Recycled HACP can be fully recycled as a pavement construction material.

Other Environmental Considerations: The use of large amounts of RAP in a mixture may increase the energy requirements of recycled HACP production at the asphalt plant. In addition if the RAP source is unknown, there is the potential to introduce some contaminants into the mix.

Recycled HACP's characteristic black surface will absorb heat from sunlight; select aggregates and pigments can be used to lighten the color and increase heat reflectivity of the surface. For recycled HACP, tire/road noise is similar to conventional HACP and is typically in the range of 66.5 to 77.5 dB(A) inside a car (80 km/hr [50 mph]) and 72 to 79.5 dB(A) at a distance 7.5 m (25 ft) from the vehicle.

AESTHETICS

Appearance: Immediately after placement, recycled HACP is generally black with a very smooth surface. Where a pigmented HACP is desired, RAP should not be added to the mix since it would introduce an unknown aggregate type and the old asphalt binder may compromise the effectiveness of the pigment. Recycled HACP could still be used for the binder course.

Appearance Degradation Over Time: Over time, recycled HACP can change color to a wide range of gray-blacks and occasionally has a brown or red sheen, depending on the predominant aggregate color. With maintenance activities, such as crack sealing and patching, the surface appearance deteriorates further. Short or medium term improvements in appearance can be achieved by the use of thin surface treatments, such as fog seals and slurry seals.

COST

Supply Price: $7.70 to $11.00/Mg ($7.00 to $10.00/ton) for RAP.

Supply+Install Price: $28 to $39/Mg ($25 to $35/ton) for recycled HACP.

EXAMPLE PROJECTS

Recycled HACP is used extensively throughout the United States, and most paving contractors routinely include RAP in hot mix production.

SELECT RESOURCES

Asphalt Institute, (859) 288-4960, www.asphaltinstitute.org
National Asphalt Pavement Association (NAPA), (888) HOT-MIXX, www.hotmix.org

FULL DEPTH RECLAMATION (FDR)

FDR - CEMENTITIOUS

GENERAL INFORMATION

Generic Name(s): Full Depth Reclamation, with Chemical Stabilization

Trade Names: N/A

Product Description: Full Depth Reclamation (FDR) is a rehabilitation technique in which the full thickness of the asphalt pavement and predetermined portion of the underlying materials (base, and sometimes, subbase) are uniformly pulverized and blended to provide an upgraded, homogenous base material. The reclaimed layer is then compacted to provide a uniform platform for the subsequent asphalt base course or surface course. FDR is an in situ process without the addition of heat. Stabilizing additives can be applied to enhance the properties of the reclaimed layer.

Three different types of stabilization can be used: bituminous (using emulsified asphalt or foamed asphalt); chemical (using portland cement, hydrated lime, cement kiln dust or lime kiln dust); and mechanical (using new granular material, RAP or crushed PCC). FDR with mechanical, bituminous and with foamed asphalt stabilizations are covered in detail in separate product summaries.

FDR with chemical stabilization is not the most commonly used form of FDR.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Asphalt Recycling & Reclaiming Association (ARRA), #3 Church Circle, PMB 250, Annapolis, MD 21401, (410) 267-0023, www.arra.org.

APPLICATION

Typical Use: Base course.

Traffic Range: Very Low to High for stabilized base applications.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: Typical FDR equipment can in situ process up to 125 to 150 mm (5 to 6 in.) of existing asphalt. Where existing asphalt thickness is greater than this, prior cold milling is required. Where there is extensive hot mix patching, the variation in asphalt thickness can pose construction problems for the FDR operation.

Other Comments: Full depth stabilized layers are commonly overlaid with HACP or covered with chip seals. FDR material has been used as a temporary road surfacing, but is not generally used as a permanent surfacing.

DESIGN

SLC: 0.15 to 0.22 depending on type of stabilizer used and quality of pulverized material.

Other Design Values: None.

Base/Subbase Requirements: The pulverized and blended material forms the new base for the reconstructed road, any underlying old base or subbase materials can be treated as subbase in design.

Other Comments: Detailed pavement evaluation is recommended before designing the FDR pavement rehabilitation. The evaluation should include visual condition survey and evaluation of pavement structural condition, using the Falling Weight Deflectometer (FWD) for instance. Pavements exhibiting major or extensive structural failures (severe alligator cracking and severe structural rutting) may require full depth base repairs.

FDR stabilization with portland cement, Type C fly ash or lime provides a significant structural component; however, it does not utilize the value of the asphalt binder in the reclaimed asphalt material. Localized full depth base repairs may be necessary in areas exhibiting severe alligator cracking and structural rutting.

CONSTRUCTION

Availability of Experienced Personnel: FDR techniques are considered to be proven in the United States; however, availability of experienced contractors for chemical stabilization is limited. Expertise is required in the preparation of the mix design for the chemical stabilization.

Materials: FDR is constructed with pulverized asphalt pavement and underlying granular material, and stabilizing additives. The additives can be portland cement, lime, fly ash, cement kiln dust and lime kiln dust. New granular materials are sometimes added for structural enhancement or for grade corrections. A bituminous sealer is generally used during the intermediate curing period where cementitious stabilizers are used.

Equipment: On typical FDR projects basic construction equipment is used: self-propelled reclaimer; motor grader; and rollers. On FDR projects including the application of a chemical stabilizing agent, additional equipment is required: haul trucks; water truck with spray bar; bulk spreader for the stabilizing agent; mixers; and tankers for slurry application.

Equipment availability may be limited in remote areas.

Full Depth Reclamation Process: Pulverization may be limited to the existing asphalt concrete or may also include a predetermined depth of the underlying granular material. Additional granular material, RAP or crushed PCC can also be added. The initial shaping of the roadway after the stabilizing additive has been added and mixed by the reclaimer, is performed with a motor grader. This is then followed with initial compaction using large pneumatic-tired or vibratory drum rollers. Final compaction and shaping to the required longitudinal profile and cross–slope is followed by a curing period. Initially moist curing is required to avoid excessive shrinkage cracking. This is followed by a period of intermediate curing when excessive drying of the mix is prevented by the use of a bituminous seal coat. The intermediate curing period is typically seven days. Heavy vehicles should be kept off the stabilized road during the curing period. A chip seal or hot mix asphalt concrete overlay is placed at the end of the curing period.

Weather Restrictions: FDR with chemical stabilization should not be performed at temperatures below freezing (0 °C [32 °F]) or when it is raining.

Construction Rate: FDR rates are on the order of 4,000 to 8,000 m^2/day (4,800 to 9,500 yd^2/day).

Lane Closure Requirements: The roadway lane being constructed is closed during construction, so adequate traffic control is needed. The FDR surface with stabilization additive can be opened to temporary traffic after an initial curing period of 12 to 24 hours. Truck traffic is not allowed until the riding surface is placed unless approved by the Contracting Officer.

Other Comments: When stabilizing granular/recycled asphalt product in-place, mixing should be limited to the depth of the granular material to prevent subgrade soils from being introduced into the mix.

With cementitious stabilization, care must be taken to avoid excessive strength being developed. Experience has shown that excessively stiff cement treated bases are prone to brittle cracking that very quickly impacts ride quality.

SERVICEABILITY

Reliability and Performance History: FDR techniques have been used for a number of years and are still gaining popularity. Research, design and construction information, and project experience is available. Case studies in the literature have reported numerous successful projects with FDR. With the use of stabilization additives, the risks are increased, since a higher structural contribution from the stabilized layer will have been assumed in design. All in situ processes have an inherent degree of risk from variation in the existing materials quality and layer thickness.

Life Expectancy: Life expectancy varies depending on treated material type, environmental conditions, traffic volumes and degree of routine maintenance. The general life expectancy falls within the following ranges: FDR with surface treatment - 7 to 10 years; and FDR with HACP overlay - 15 to 20 years.

Ride Quality: If overlaid with HACP, FDR stabilized pavement can provide very good ride quality after construction.

Main Distress / Failure Modes: Rutting, cracking, similar to the distress modes for conventional flexible pavements provided the stabilized layer is not excessively stiff.

Preservation Needs: No preventative maintenance is typically required because FDR layers are not used as a surfacing.

SAFETY

Hazards: None.

Skid Resistance: When used as a temporary road surfacing, FDR layers can provide adequate skid resistance.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: FDR is generally performed on in situ road materials. Cementitious and chemical stabilizers are manufactured or produced as byproducts of other industries. Asphalt cement is an asphalt product produced by distillation of crude oil. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: Portland cement, lime and other stabilizing additives must be hauled from manufacturers or suppliers. Haul distances may be significant for remote sites. The cost effectiveness of this type of FDR stabilization can be largely controlled by the haul distances of the stabilization agents.

Potential Short-Term Construction Impacts: A certain amount of noise is associated with the process. Construction processes may impact vegetation adjacent to the roadway.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Portland cement and lime stabilized layers are considered to be impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by FDR.

Erosion: FDR is generally protected with a surfacing layer and thus is not susceptible to erosion.

Water quality: FDR does not impact water quality.

Aquatic species: FDR does not impact aquatic species.

Plant quality: FDR does not impact plant quality.

Air Quality: FDR does not impact air quality.

Other: None.

Ability to Recycle/Reuse: It is generally assumed that FDR with cementitious or chemical stabilization can be fully recycled and reused as a pavement construction material. However, there are few documented case studies of the practicalities of this form of secondary recycling.

Other Environmental Considerations: None.

AESTHETICS

Appearance: The pulverized pavement resulting from FDR is generally not left exposed. The appearance is similar to a stabilized aggregate base material.

Appearance Degradation Over Time: N/A; FDR pavement layers are not exposed as a surfacing.

COST

Supply Price: N/A

Supply+Install Price: \$4.00 to \$7.00/m^2 (\$3.30 to \$5.90/yd^2), depending on the application rate of cement, for a mixing depth of 150 to 200 mm (6 to 8 in.).

EXAMPLE PROJECTS

South Loop Road, Theodore Roosevelt National Park, ND.

SELECT RESOURCES

Asphalt Recycling & Reclaiming Association (ARRA), (410) 267-0023, www.arra.org
ARRA (2001). *Basic Asphalt Recycling Manual*, Publication No. NHI01-022, American Recycling and Reclaiming Association, 270 pp.

FDR- EMULSIFIED ASPHALT

GENERAL INFORMATION

Generic Name(s): Full Depth Reclamation, with Bituminous Stabilization

Trade Names: N/A

Product Description: Full Depth Reclamation (FDR) is a rehabilitation technique in which the full thickness of the asphalt pavement and predetermined portion of the underlying materials (base, and sometimes, subbase) are uniformly pulverized and blended to provide an upgraded, homogenous base material. The reclaimed layer is then compacted to provide a uniform platform for the subsequent asphalt base course or surface course. FDR is an in situ process without the addition of heat. Stabilizing additives can be applied to enhance the properties of the reclaimed layer.

Three different types of stabilization can be used: bituminous (using emulsified asphalt or foamed asphalt); chemical (using portland cement, hydrated lime, cement kiln dust or lime kiln dust); and mechanical (using new granular material, RAP or crushed PCC). FDR without stabilization, with mechanical, chemical, and foamed asphalt stabilizations are covered in detail in separate product summaries.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Asphalt Recycling & Reclaiming Association (ARRA), #3 Church Circle, PMB 250, Annapolis, MD 21401, (410) 267-0023, www.arra.org.

APPLICATION

Typical Use: Base course.

Traffic Range: Very Low to High for stabilized base applications.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: Typical FDR equipment can in situ process up to 125 to 150 mm (5 to 6 in.) of existing asphalt. Where existing asphalt thickness is greater than this, prior cold milling is required. Where there is extensive hot mix patching, the variation in asphalt thickness can pose construction problems for the FDR operation.

Other Comments: Full depth stabilized layers are commonly overlaid with hot mix asphalt concrete or covered with chip seals. FDR and stabilized FDR can be used as a temporary road surfacing, but are not generally suitable for permanent road surfacing.

DESIGN

SLC: 0.20 to 0.30 for full depth emulsified asphalt stabilization.

Other Design Values: None.

Base/Subbase Requirements: The pulverized and blended material forms the new base for the reconstructed road, any underlying old base or subbase materials can be treated as subbase in design.

Other Comments: Detailed pavement evaluation is recommended before designing the FDR pavement rehabilitation. The evaluation should include visual condition survey and evaluation of pavement structural condition, using the Falling Weight Deflectometer (FWD) for instance. Pavements exhibiting major or extensive structural failures (severe alligator cracking and severe structural rutting) may require full depth base repairs.

FDR bituminous stabilization provides a significant structural component and it utilizes the value of the asphalt binder in the reclaimed asphalt material. However, where the existing road is determined to have structural deficiencies, the FDR process may not be adequate for rehabilitation. If the pavement exhibits severe structural distresses such as alligator cracking and structural rutting, full depth base or subgrade repairs and drainage improvements/installations may be necessary.

CONSTRUCTION

Availability of Experienced Personnel: FDR techniques are considered to be proven in the United States. Expertise is required in establishing the appropriate mix design based on the properties of the in situ materials to be pulverized and stabilized.

Materials: FDR is constructed with pulverized asphalt pavement and underlying granular material, and stabilizing additives. The emulsified asphalt is sometimes added in conjunction with other additives, such as portland cement or Type C fly ash slurry, to reduce initial curing period, accelerate strength gain and reduce moisture susceptibility. New granular materials are sometimes added for structural enhancement or for grade corrections.

Equipment: On typical FDR projects basic construction equipment is used: self-propelled reclaimer; motor grader; and rollers. On FDR projects including the application of a stabilizing agent, additional equipment is required: haul trucks; aggregate spreader; water truck with spray bar; bulk spreader for the stabilizing agent; mixers and tankers for slurry application; and emulsion tanker and distributor truck.

Equipment availability may be limited in remote areas.

Full Depth Reclamation Process: Pulverization may be limited to the existing asphalt concrete or may also include a predetermined depth of the underlying granular material. Additional granular material, RAP or crushed PCC can also be added. The initial shaping of the roadway after the stabilizing additive has been added and mixed by the reclaimer, is performed with a motor grader. This is then followed with initial compaction using large pneumatic-tired or vibratory drum rollers. Final compaction and shaping to the required longitudinal profile and cross–slope is followed by a curing period, if a stabilizing agent has been used. The initial curing period depends on the type of stabilizing additives used and the ambient conditions; but it typically ranges from a few hours to a day, after which the road can be opened to traffic. Where possible, heavy vehicles should be kept off the stabilized base until the surfacing has been added. The intermediate curing period, prior to placement of surfacing, can take up to 14 days depending on weather conditions. A chip seal or HACP overlay is placed at the end of the intermediate curing period.

Weather Restrictions: FDR should not be performed at temperatures below freezing (0 °C [32 °F]) or when it is raining. Full depth emulsion stabilization should not be used during cold (temperature less than 10 °C [50 °F]) and/or rainy weather.

Construction Rate: FDR rates are on the order of 4,000 to 8,000 m^2/day (4,800 to 9,500 yd^2/day).

Lane Closure Requirements: The roadway lane being constructed is closed during construction, so adequate traffic control is needed. The FDR surface, even without stabilization additive, can generally be opened to vehicular traffic at reduced speeds as soon as construction is complete and construction equipment is cleared from the roadway.

Other Comments: When stabilizing granular/recycled asphalt product in-place, mixing should be limited to the depth of the granular material to prevent subgrade soils from being introduced into the mix.

With asphalt emulsion stabilization, traffic will have to run on the stabilized surface until curing is complete. A surfacing layer applied before the completion of the curing period will be prone to debonding from the stabilized layer.

SERVICEABILITY

Reliability and Performance History: FDR techniques have been used for a number of years and are still gaining popularity. Research, design and construction information, and project experience is available. Case studies in the literature have reported numerous successful projects with FDR. All in situ processes have an inherent degree of risk from variation in the existing materials quality and layer thickness. With the use of stabilization additives, the risks are increased, since a higher structural contribution from the stabilized layer will have been assumed in design.

Life Expectancy: Life expectancy varies depending on treated material type, environmental conditions, traffic volumes and degree of routine maintenance. The general life expectancy falls within the following ranges: FDR with surface treatment - 7 to 10 years; and FDR with HACP overlay - 15 to 20 years.

Ride Quality: If overlaid with HACP, FDR stabilized pavement can provide very good ride quality after construction.

Main Distress / Failure Modes: Rutting, cracking, similar to conventional flexible pavements. The stabilized base layer can be prone to stripping if not adequately protected.

Preservation Needs: No preventative maintenance is typically required because FDR layers are not used as a surfacing.

SAFETY

Hazards: None.

Skid Resistance: When used as a temporary road surfacing, FDR layers can provide adequate skid resistance.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: FDR is generally performed on in situ road materials. Asphalt cement is an asphalt product produced by distillation of crude oil. Emulsifying agents (for emulsified asphalt) are manufactured products. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: Emulsified asphalt must be hauled from an asphalt plant. Portland cement, lime and other stabilizing additives must be hauled from manufacturers. Haul distances may be significant for remote sites.

Potential Short-Term Construction Impacts: A certain amount of noise is associated with the process. Construction processes may impact vegetation adjacent to the roadway.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Bituminous stabilized layers are considered to be impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by FDR.

Erosion: FDR is generally protected with a surfacing layer and thus is not susceptible to erosion.

Water quality: FDR does not impact water quality.

Aquatic species: FDR does not impact aquatic species.

Plant quality: FDR does not impact plant quality.

Air Quality: FDR does not impact air quality.

Other: None.

Ability to Recycle/Reuse: FDR can be fully recycled and reused as a pavement construction material.

Other Environmental Considerations: None.

AESTHETICS

Appearance: The pulverized pavement resulting from FDR is generally not left exposed. The appearance of the asphalt stabilized base is darker than conventional aggregate base material, but lighter than HACP. It presents a stabilized surface with a relatively rough finish.

Appearance Degradation Over Time: N/A; FDR pavement layers are not exposed as a surfacing.

COST

Supply Price: N/A

Supply+Install Price: \$5.00 to \$8.00/m^2 (\$4.20 to \$6.70/yd^2), depending on the quantity of asphalt emulsion needed, for a mixing depth of 150 to 200 mm (6 to 8 in.).

EXAMPLE PROJECTS

Point Road, Chickasaw National Recreation Area, OK.
Rockcreek & New Market Drives, City of Delaware, OH.

SELECT RESOURCES

Asphalt Recycling & Reclaiming Association (ARRA), (410) 267-0023, www.arra.org.
ARRA (2001). *Basic Asphalt Recycling Manual*, Publication No. NHI01-022, American Recycling and Reclaiming Association, 270 pp.

FOAMED ASPHALT

GENERAL INFORMATION

Generic Name(s): Foamed Asphalt, Expanded Asphalt, Foamed Bitumen

Trade Names: N/A

Product Description: Foamed asphalt is a stabilization technique where asphalt cement is used to bind existing or new granular material into a flexible base or subbase layer. Foamed asphalt is constructed with hot asphalt cement and cold water as a foaming agent. When the hot asphalt cement, typically 160 to 200 °C (320 to 390 °F), comes in contact with cold water, typically 15 to 25 °C (60 to 77 °F), the mixture expands to more than ten times its original volume and is separated into very fine droplets. The foamed material is mixed with the granular material to be stabilized and coats the fines in the granular material to form a mortar that binds the coarse particles together. The resulting product is a well mixed stabilized base material.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: National Asphalt Pavement Association, 5100 Forbes Blvd., Lanham, MD 20706, (888) HOT-MIXX, www.hotmix.org; and

Asphalt Recycling & Reclaiming Association (ARRA), #3 Church Circle, PMB 250, Annapolis, MD 21401 www.arra.org.

APPLICATION

Typical Use: Base stabilization, binder course.

Traffic Range: Very Low to High for base stabilization applications.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: Foamed asphalt can be used to stabilize sand, coarse aggregates, or milled asphalt products. The material to be stabilized must have enough fines content (5% to 20%) for the foamed asphalt to bind with to adequately stabilize the material. If the material contains high plasticity fines, additives (e.g. lime, cement, etc.) are often mixed with the material prior to foamed asphalt stabilization.

Other: None.

Other Comments: Compared to other asphalt stabilization techniques, foamed asphalt requires less water and asphalt cement and is better suited for use with marginal materials containing large amounts of fines. Foamed asphalt-stabilized base is commonly overlaid with a thin asphalt concrete layer; fog seals, slurry seals, and chip seals have also been used as a surfacing. Foamed asphalt-stabilized material has been used as a temporary road surfacing, but is not generally used as a permanent surfacing.

DESIGN

SLC: 0.25 (sands and marginal quality aggregates) to 0.40 (high quality granular aggregates).

Other Design Values: None.

Base/Subbase Requirements: Roadway should be designed with adequate base and/or subbase support.

Other Comments: The grade of asphalt cement needs to be selected based on service temperature ranges. Generally, a neat (unmodified) asphalt is necessary to attain the proper foaming characteristics. Highly modified asphalts will often not be able to achieve the proper expansion and half-life (i.e. a measure of the working life of the foam before it dissipates). Typical application rates for foamed asphalt are 2% to 4%.

No long-term durability issues (e.g. freeze-thaw or moisture susceptibility) have been identified to this point. Additional research is needed in this area.

CONSTRUCTION

Availability of Experienced Personnel: Foamed asphalt is a fairly new stabilization technique and availability of experienced contractors is, in general, limited.

Materials: Foamed asphalt is constructed with hot asphalt cement and cold water as a foaming agent.

Equipment: Equipment required for foamed asphalt stabilization construction includes: tanker truck for asphalt, specialized pulverizer (reclaimer) with a foamed asphalt injection system, water truck, compaction equipment, and a motor grader. Equipment availability may be limited in remote areas.

Manufacturing/Mixing Process: Foamed asphalt can be plant-mixed or mixed in place. In-place mixing typically occurs when a granular material is already located on site or when existing pavements in need of complete reconstruction are pulverized into a granular material and cold recycled to create a stabilized base for a new road surfacing.

Placement Process: Foamed asphalt is constructed with hot asphalt cement and cold water as a foaming agent. The foamed asphalt is mixed with the material to be treated using a specialized pulverizer (reclaimer) with a foamed asphalt injection system. Depending on the reclaimer used, the process can either be completed in a single pass or the material may be pre-pulverized prior to foamed asphalt stabilization. The hot asphalt, typically 160 to 200 °C (320 to 390 °F), and cold water are combined at a controlled rate on board the reclaimer. This causes the asphalt cement to foam and expand to more than ten times its normal value. The foamed asphalt is then introduced to the pulverized material in the mixing chamber of the reclaimer through a spray bar mounted on the hood of the mixing chamber. The foamed material mixes with the granular material and coats the fines in the granular material to form a mortar that binds the coarse particles together. Most of the water in the mixture is released as steam and the remaining stabilizer, consisting mainly of asphalt cement, returns to its original volume. The resulting product is a well mixed stabilized base material. A high quality road surface can be achieved with only the application of a thin surfacing.

Weather Restrictions: Foamed asphalt stabilization should not be performed at temperatures below freezing (0 °C [32 °F]) or when it is raining.

Construction Rate: Foamed asphalt stabilization rates are on the order of 4,000 to 6,500 m^2/day (4,800 to 7,800 yd^2/day).

Lane Closure Requirements: The roadway lane(s) being constructed are closed during construction, so adequate traffic control is needed. The foamed asphalt-stabilized surface can be opened to traffic on a temporary basis as soon as construction is complete and construction equipment is cleared from the roadway.

Other Comments: When stabilizing granular/recycled asphalt product in-place, mixing should be limited to the depth of the granular material to prevent subgrade soils from being introduced into the mix. The typical processing depth is 150 mm (6 in.).

SERVICEABILITY

Reliability and Performance History: Foamed asphalt stabilization is a relatively recent stabilization technique in North America, but has gained popularity over the past several years, because of its cost-effectiveness. Research, design and construction information, and project experience is available. Case studies in the literature have reported very good success with foamed asphalt.

Life Expectancy: Life expectancy varies depending on treated material type, environmental conditions, traffic volumes and degree of routine maintenance. Typical serviceable lives range from 15 to 20 years or longer for foamed asphalt-stabilized base with a HACP surfacing. When covered by a thin surface treatment, typical serviceable lives for the foamed asphalt-stabilized base layer are 8 to 12 years for low volume applications.

Ride Quality: Foamed asphalt can provide good to very good ride quality after construction.

Main Distress / Failure Modes: Cracking (within the stabilized layer).

Preservation Needs: No preventative maintenance is typically required because foamed asphalt is not used as a surfacing.

SAFETY

Hazards: None.

Skid Resistance: When used as a temporary road surfacing, foamed asphalt provides adequate skid resistance.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: Foamed asphalt is an in situ treatment. Asphalt cement is an asphalt product produced by distillation of crude oil. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: Asphalt cement must be hauled from a stationary asphalt plant. However, the quantities are relatively small since only 2 to 4% asphalt cement needs to be added. Haul distances may be significant for remote sites. When foamed asphalt is used to stabilize existing in-place materials, no aggregate hauling is required.

Potential Short-Term Construction Impacts: None.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Foamed asphalt is impermeable, which promotes surface runoff. However, surface runoff water quality is not generally impacted by foamed asphalt stabilization.

Erosion: None.

Water quality: None.

Aquatic species: None.

Plant quality: None.

Air Quality: None.

Other: None.

Ability to Recycle/Reuse: Foamed asphalt can be fully recycled as a pavement construction material.

Other Environmental Considerations: None.

AESTHETICS

Appearance: Immediately after construction, foamed asphalt generally takes on the color characteristics of the material being treated.

Appearance Degradation Over Time: Foamed asphalt is not exposed as a surfacing material.

COST

Supply Price: N/A

Supply+Install Price: \$4.80 to \$8.40/m^2 (\$4.00 to \$7.00/yd^2) for a mixing depth of 150 mm (6 in.).

EXAMPLE PROJECTS
Marysville Road, Yuba County, CA. Trail Ridge Road, Rocky Mountain National Park, CO. Canyon de Chelly National Monument, AZ.
SELECT RESOURCES
Wirtgen, *Wirtgen Cold Recycling Manual*, Wirtgen GmbH, ISBN 3-00-003577-X, 1998

PULVERIZATION

GENERAL INFORMATION

Generic Name(s): Full Depth Reclamation

Trade Names: N/A

Product Description: Full Depth Reclamation (FDR) is a rehabilitation technique in which the full thickness of the asphalt pavement and predetermined portion of the underlying materials (base, and sometimes, subbase) are uniformly pulverized and blended to provide an upgraded, homogenous base material. The reclaimed layer is then compacted to provide a uniform platform for the subsequent asphalt base course or surface course. FDR is an in situ process without the addition of heat. Stabilizing additives can be applied to enhance the properties of the reclaimed layer. FDR with bituminous and chemical stabilization are covered in detail in separate product summaries.

The structural support of the pulverized in situ pavement materials can be enhanced by the addition of granular materials such as virgin aggregates, reclaimed granular materials, crushed/reclaimed PCC, or reclaimed asphalt pavement (RAP). These additional granular materials can improve gradation deficiencies and drainage characteristics of the compacted base.

Product Suppliers: Representative list of manufacturers, suppliers, and contractors can be obtained from: Asphalt Recycling & Reclaiming Association (ARRA), #3 Church Circle, PMB 250, Annapolis, MD 21401, (410) 267-0023, www.arra.org.

APPLICATION

Typical Use: Base course.

Traffic Range: Very Low to High, similar to any aggregate road base application.

Restrictions:

Traffic: None.

Climate: None.

Weather: None.

Terrain: None.

Soil Type: N/A

Other: Typical FDR equipment can in situ process up to 125 to 150 mm (5 to 6 ins.) of existing asphalt. Where existing asphalt thickness is greater than this, prior cold milling is required. Where there is extensive hot mix patching, the variation in asphalt thickness can pose construction problems for the FDR operation.

Other Comments: Pulverized pavement will perform as an unbound granular surface and can be used for temporary construction traffic without additional surfacing, but is not generally suitable for use as a permanent surfacing.

DESIGN

SLC: 0.10 to 0.15 for pulverized asphalt pavement mixed with existing granular material.

Other Design Values: None.

Base/Subbase Requirements: The pulverized and blended material forms the new base for the reconstructed road, any underlying old base or subbase materials can be treated as subbase in design. New base aggregates can be added to achieve increased base structural support or for geometric adjustments.

Other Comments: Detailed pavement evaluation is recommended before designing the FDR pavement rehabilitation. The evaluation should include visual condition survey and evaluation of pavement structural condition, using the Falling Weight Deflectometer (FWD) for instance. Pavements exhibiting major or extensive structural failures (severe alligator cracking and severe structural rutting) may require full depth base repairs.

CONSTRUCTION

Availability of Experienced Personnel: FDR techniques are considered to be proven in the United States. FDR without bituminous or chemical stabilization is a low risk process.

Materials: FDR is constructed with pulverized asphalt pavement and underlying granular materials. New granular materials, RAP, or crushed PCC can be used in mechanical stabilization and added to enhance the structural quality of the completed base.

Equipment: On typical FDR projects basic construction equipment is used: self-propelled reclaimer; motor grader; and rollers. Other equipment that may be needed includes haul trucks; aggregate spreader; and water trucks to aid in achieving compaction.

Equipment availability may be limited in remote areas.

Full Depth Reclamation Process: Pulverization may be limited to the existing asphalt concrete or may also include a predetermined depth of the underlying granular material. Additional granular material, RAP or crushed PCC can also be added. The initial shaping of the roadway after pulverization and blending is performed with a motor grader. This is then followed with initial compaction using large pneumatic-tired or vibratory drum rollers and final compaction and shaping to achieve the required longitudinal profile and cross–slope. A chip seal or HACP overlay can be placed as soon as the specified compaction is achieved.

Weather Restrictions: FDR should not be performed at temperatures below freezing (0 °C [32 °F]) or when it is raining, due to the difficulties of achieving compaction.

Construction Rate: FDR rates are on the order of 4,000 to 8,000 m^2/day (4,800 to 9,500 yd^2/day).

Lane Closure Requirements: The roadway lane being constructed is closed during construction, so adequate traffic control is needed. The FDR surface can generally be opened to temporary traffic as soon as construction is complete and construction equipment is cleared from the roadway.

Other Comments: Generally, FDR equipment can process to the edge of a curb and gutter section, however, for straight-faced concrete sections (with no gutter), a portion of roadway will have to be removed with smaller equipment.

SERVICEABILITY

Reliability and Performance History: FDR techniques have been used for a number of years and are still gaining popularity. Research, design and construction information, and project experience is available. Case studies in the literature have reported numerous successful projects with FDR. FDR without stabilization is very low risk and the existing granular base is enhanced by the addition of the RAP. All in situ processes have an inherent degree of risk from variation in the existing materials quality and layer thickness.

Life Expectancy: Life expectancy varies depending on treated material type, environmental conditions, traffic volumes and degree of routine maintenance. The general life expectancy falls within the following ranges: FDR with surface treatment - 7 to 10 years; and FDR with HACP - 15 to 20 years.

Ride Quality: If overlaid with HACP, pavements with full depth reclaimed bases provide very good ride quality after construction.

Main Distress / Failure Modes: Rutting and cracking, as for conventional flexible pavements.

Preservation Needs: No preventative maintenance is typically required because FDR layers are not used as a surfacing.

SAFETY

Hazards: None.

Skid Resistance: When used as a temporary road surfacing, FDR layers can provide adequate skid resistance.

Road Striping Possible?: N/A; not a surfacing.

Other Comments: None.

ENVIRONMENTAL CONCERNS

Source of Raw Materials: FDR is generally performed on in situ granular and bituminous bound road materials. Asphalt cement is an asphalt product produced by distillation of crude oil. Aggregates may be naturally occurring or quarried, but either requires mechanical processing (crushing, sizing) before they can be used.

Delivery and Haul Requirements: When FDR is used to treat existing in-place materials, no aggregate hauling is required. Additional aggregates to enhance the in situ properties, where required, would need to be hauled to site from commercial sources.

Potential Short-Term Construction Impacts: A certain amount of noise is associated with the process. Construction processes may impact vegetation adjacent to the roadway.

Potential Long-Term Environmental Impacts:

Leachate: None.

Surface Runoff: Surface runoff water quality is not generally impacted by FDR.

Erosion: FDR is generally protected with a surfacing layer and thus is not susceptible to erosion.

Water quality: FDR does not impact water quality.

Aquatic species: FDR does not impact aquatic species.

Plant quality: FDR does not impact plant quality.

Air Quality: FDR does not impact air quality.

Other: None.

Ability to Recycle/Reuse: FDR can be fully recycled and reused as a pavement construction material.

Other Environmental Considerations: None.

AESTHETICS

Appearance: The pulverized pavement resulting from FDR is generally not left exposed. The appearance is similar to a dark aggregate base material, with the asphalt coated particles visible on close examination.

Appearance Degradation Over Time: N/A; the pulverized pavement is not exposed as a surfacing material.

COST

Supply Price: N/A

Supply+Install Price: \$2.00 to \$4.00/m^2 (\$1.70 to \$3.30/yd^2), for a typical 200 mm (8 inch) processing depth.

EXAMPLE PROJECTS

Used extensively for municipal road rehabilitation throughout the United States.

SELECT RESOURCES

Asphalt Recycling & Reclaiming Association (ARRA), (410) 267-0023, www.arra.org.
ARRA (2001). *Basic Asphalt Recycling Manual*, Publication No. NHI01-022, American Recycling and Reclaiming Association, 270 pp.