Low-Cost Asphalt-Surfaced Roads

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A variety of low-cost asphalt road-surfacing techniques and a unique technology transfer method used to gather information are discussed. The premise is that the employees of the U.S. Department of Agriculture, Forest Service, have a large amount of knowledge and experience on low-cost asphalt-surfaced roads; however, little of it is formally documented. The technology transfer was accomplished by creating an electronic forum that is readily available to this large group of employees. The process facilitated an open discussion of the topic and brought together knowledge and experience from this diverse group of engineers, who are located throughout the United States. The data include numerous processes such as asphalt surface treatments, oil mats, road mixes, desert mixes, and sand seals. Design methods as well as test data are presented. The information, while largely originating from experiences and examples west of the Rocky Mountains, has application to many other locations.

Asphalt concrete has become the standard road-surfacing material for primary, secondary, and many local roads in the United States. Many miles of roads surfaced with native material and aggregates throughout the nation still need to be upgraded.

Asphalt concrete (AC) surfacing is desirable but costly when compared to aggregate surfacing. Native materials and aggregate surfacing are less desirable but cheaper to construct. There are many miles of existing treated roads throughout the United States that fall between these two categories. Many are surfaced with a mixture of asphalt material combined with a small amount of graded aggregate or native material. Often they have performed well for many years. These surfaces are referred to as "low-cost asphalt-surfaced roads" (LCASRs).

Processes included in LCASRs are numerous and are referred to by a variety of names. Some of them are well known and many are local. The processes include asphalt surface treatments, oil mats, road mixes, desert mixes, and sand seals.

Quite a bit of information is available from the Asphalt Institute and other sources for the relatively higher-cost surfaces, but little information seems to exist for the less costly alternatives. These lower-cost "alternatives" are found, in some cases, to perform as well as the more costly processes. Local roads surfaced with sand and asphalt and decomposed granite-asphalt mixes have been observed on the Inyo, Sequoia, and Mendocino National Forests in California (unpublished internal reports, U.S. Forest Service). The problem is to find out which will be successful for a particular situation, under what conditions, what specifications should be used, what are the costs, and what materials will work.

Another class of low-cost surfaces consists of chemical treatments with materials such as lignin sulfonate, magnesium chloride, and proprietary products such as Biocat. It was originally intended to include this class of materials herein; however, insufficient data were gathered during this study to adequately cover the subject.

The Forest Service has a tremendous amount of experience and knowledge in low-volume road technology; however, much of it is not formally documented. As much of this information as possible was pulled together along with references and other data from local road agencies and individuals working in these areas.

TECHNOLOGY TRANSFER PROCESS

To gather information, a unique technology transfer (T2) process was begun in the Pacific southwest region (California) of the Forest Service in May 1988. The process consists of engineering T2 coordinators located agencywide who are in contact with road specialists in their local areas and are linked together by an interactive computer network. Information received from them was then shared through the same network in summary form and filed for compilation. The information received included

- Specific LCASR project experience;
- References, texts, literature, newsletters, etc.;
- Names of individuals who have LCASR experience; and
- LCASR design guides.

A large amount of comments and information was received, including design guides for asphalt surface treatments and detailed plans and specifications for rehabilitation work on distressed pavements. In addition, a number of references were suggested for use on various parts of LCASRs.

Most of the information came from 32 Forest Service employees located on 18 national forests in six regions plus the Washington office. The employees consisted of forest engineers, geotechnical engineers, materials engineers, maintenance engineers, and others.

The T2 process had a dual purpose: (a) to gather information, and (b) to provide immediate benefit through feedback of information and contacts for help to those in the agency who were designing, building, and maintaining LCASRs.

The information gathered through this effort and through additional literature searches has been compiled into a synthesis of options for LCASR design, costing, construction, and maintenance.

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TYPES OF LOW-COST ASPHALT-SURFACED ROADS

Road Mixes

The term "road mixes" means different things to different people; therefore a definition is needed. Road mixes are considered to consist of treatment of the top (1 in. to several inches) of the existing road surface by means of adding asphalt or other additive, mixing, and compacting in place. In some cases, additional surfacing material may be added before treatment; however, the distinction between road mixes and other types of road surfaces is that the mixing is done on the road, as the name implies.

Road mixing is normally done in one of two ways: (a) by a traveling pugmill or cross-shaft mixer, or (b) by windrow mixing with a motor grader (blade). The traveling mixer is preferred because the end product is a more uniform mix and will have better depth control. Unfortunately, traveling mixers are hard to find at times. A good grader operator can produce an acceptable mix, but good grader operators with blade mixing experience are also scarce [Gordon Keller, Mailing 2 in *Low Cost Road Surfaces* (LCRS) *Data Summary*, unpublished; all LCRS mailings referred to in this paper are available from E. J. Mandingo, U.S. Forest Service, Pleasant Hill, California].

A road-mixing alternative will normally not be competitive with other alternatives if much of the crushed aggregate must be imported any distance. If the road requires new material, consider mixing the aggregate with asphalt or other additive at the aggregate source by means of a stationary pugmill. The end product will be better, although costlier than if existing material can be treated in place.

One of the common pavements found in the Sierras is what is sometimes called a "desert mix." It is quite common to find a fairly major rural road of this type that has been handling traffic for 15 to 20 years with little distress. Often the pavement consists of a mixture of asphalt and native decomposed granite (DG) and has been chip sealed periodically similar to higher-type pavements. History of the construction of these roads is hard to find and the practice does not seem to be common anymore. One of the major reasons for the success of these roads is the structurally sound nature of the DG soils because of their nonplastic and generally well-drained characteristics. The asphalt was probably a cut-back (MC or SC). The MCs may be a problem now because of air quality restrictions.

A similar road surface was produced with a cinder aggregate road mix constructed on the Rice Canyon Road on the Tahoe National Forest in about 1973 (Stephan Johnson, Forest Service, unpublished data). An SSK-h cationic emulsified asphalt (current designation is CSS-1h) was mixed on the road with a Woods™ traveling pugmill. An asphalt content of approximately 14 percent (by total weight) was required. The high percentage was caused by the porous nature of the cinders and their low weight (110 lb/ft^3). The mixture appeared initially to be wet from the high percentage of fluids, but apparently worked well, because it is still in use today.

Other native materials have been used for road mixing with various degrees of success. Volcanic cinders and pumice have also been used in eastern Oregon by counties and by the Forest Service (John Lund, Oregon Institute of Technology, unpublished data).

Cold Mixes

Cold-mix asphalt pavements are on the high end of LCASRs and were quite popular in the mid-1970s. Many miles were constructed by the Forest Service in both the Pacific Northwest and the Pacific Southwest Regions (in Oregon, Washington, and California). Cold mixes are generally produced at a stationary pugmill mixer often set up at the crusher or stockpile site. The mix usually consists of a crushed-rock aggregate of a single gradation blended together with an emulsified asphalt that is metered into the aggregate in the pugmill.

A cold-mix project was constructed on the Tom Young road (Ron Andrus, LCRS Mailing 4, unpublished) many years ago, which used SSK-h emulsified asphalt mixed with screened cinders. The pugmill was set up downstream from the screen and the mix was placed on the road with a conventional paving machine to 3-in. depth. The material is still in place; however, most of the original cold mix has been recycled into base material and more base was added to correct the deficient structural strength. Approximately 3 mi of the original surface remains in use today.

Another interesting construction material that is planned for use in Routt County, Colorado, is a tar sand (a naturally occurring petroleum-sand mixture) imported from beds near Vernal, Utah. Routt County plans to crush the material when cold, blend 40/60 with crushed aggregate, then lay it on the roadway and compact it. This technique has been used around Vernal, Utah, and Dinosaur, Colorado, with excellent results and appears to cost less than half of what it would for conventional asphalt concrete. Transportation costs and limited sources will limit its use (Rex V. Blackwell, LCRS Mailing 6, unpublished).

Because control of most of the cold-mix processes is less precise than hot-mix asphalt concrete, the strength factors used to compute thickness are generally considered to be between 70 and 80 percent of those used for hot mix. This procedure results in a thicker pavement section, reducing the cost advantage of the cold mix. In situations where existing structural strength of the road is adequate, cold mixes usually have an economic advantage over hot mixes. Other solutions such as surface treatments can prove to be more economical in some moderate traffic and environmental conditions.

Technical information for the design and construction of cold mixes is published by the Asphalt Institute. Two publications that are especially useful are *Asphalt Cold Mix Manual* (*1*) and *Basic Asphalt Emulsion Manual* (*2*).

Penetration Treatments

Penetration treatments or prime coats are normally not considered as a surfacing type by themselves, but are included here because of some limited use in isolated situations. Occasionally, a prime coat is applied preparatory to paving or a surface treatment and it becomes necessary to carry traffic for an extended period of time on its surface. This practice, although not recommended, can be successful providing the base is adequate; cross section, vertical alignment, and horizontal alignment are not too severe; and traffic weights and speeds are not excessive. Ambient temperature as well as the tightness (i.e., the ability of the prime to penetrate into the base surface) also play an important part in the success. If ambient temperatures are high, some cover or blotter material will be necessary to prevent bleeding and pick-up of the asphalt.

Asphalt used for prime coats is usually an MC cutback; however, because of environmental considerations discussed later, emulsions are becoming more widely used for this purpose. A good asphalt reference such as *The Asphalt Handbook* (*3*), published by the Asphalt Institute, should be consulted for design of prime coats.

Asphalt Surface Treatments

Asphalt surface treatments are probably the most widely used of the LCASR treatments on Forest Service roads in the west during the last decade or so. There are many names, many of which are descriptive of the individual process. Some of the more common ones will be described here.

Fog Seals

Fog seals are generally a light application of emulsified asphalt applied to the surface of an AC pavement. They were used extensively in the west during the 1950s and into the 1960s to seal new pavements immediately after paving. They fell out of favor with many agencies, however, because of the tendency for the pavement surfaces to become very slippery when wet and to bleed easily in hot weather. These problems were largely caused by excessive application or inappropriate choice of seal materials because of inadequate or unused surface evaluation methods. The cure was to burn the excess asphalt off with a large vehicle-mounted propane burner, which also caused additional problems of high cost and air pollution. Fog seals have a limited place in the rehabilitation of oxidized or otherwise distressed pavements as well as for low-traffic areas such as parking lots.

Seal Coats

Seal coat is a generic term that is commonly used for a number of surface treatments applied to a paved surface and includes fog seals and chip seals.

Chip Seals

Chip seals (or single-chip seals) commonly refer to sealing of existing pavements, similar to fog seals, except that additional emulsified asphalt is used and it is blotted or covered with a fine aggregate; usually a single-size crushed chip with a maximum size of ¼ or ⅜ in.; ½- and ⅝-in. chips have been used successfully on roads with heavy truck traffic to extend chip life by reducing embedment.

Successful chip seals have also been constructed using natural occurring sands and decomposed granite on national forests in the southern and central Sierras as well as with cinders and pumice in northern California and central Oregon. Dust is often a problem with native materials, however. Dust-free aggregate is important to chip seal success.

The first seal is often delayed until 5 to 7 years after the road is paved. Subsequent seals are usually needed on about a 5-year cycle. Chip seals avoid both the common drawbacks of the fog seals because of their superior traction characteristics and less chances for an overly rich application.

Perhaps this discussion on pavement sealing seems out of place for LCASRs; however, sealing is one of the primary repairs for badly deteriorated pavements and as such may be useful to a road agency to stabilize and retain some of the value of an apparently lost pavement.

Single-chip seals can also constitute the entire LCASR treatment applied directly to an aggregate base or a native material road surface. In this form, they are applied like the penetration treatments except that the quantity and grades of asphalt are selected to retain the cover aggregate as well as penetrate the base. Another similarity is the need for a well-drained base that possesses structural strength adequate for the loads that will be imposed on it (Forest Service LCRS Mailings 4, 6, 8, 12, 15, and 18, unpublished). A single-chip seal has little structural strength; however, it is flexible and can survive some base deflection without failing. Chip seals used in this manner can also be constructed with a variety of aggregates, both manufactured or native, and can be expected to last for many years of light service if properly maintained. Maintenance needs vary depending on many variables including

- Traffic volume, weight, and speed;
- Weather; and
- Road alignment, vertical and horizontal.

Forest Service engineers in the Northern Region (Montana, northern Idaho, North Dakota, and northwestern South Dakota) (Steve Monlux and Bob Hinshaw, LCRS Mailing 8, unpublished) recommend the first maintenance seal coat be applied in 1 to 3 years with additional treatments every 3 to 5 years. Actual application of seal coats, particularly in the west coast states, is usually less frequent.

Multiple-Chip Seals

Multiple-chip seals are the most common and probably the most successful of the LCASR types that were reported. The reasons are several: they are more common (therefore contractors and engineers are more experienced in their design and construction), the construction process is somewhat less critical than for cold mixes, and reliable procedures are available and are well documented. A multiple-chip seal may consist of from two to as many as five applications of asphalt with alternating spreads of aggregate. Typically two or three applications are used with the first one being a penetration spread. Obviously, the more numerous applications are more costly and will not compete well from a cost standpoint when compared to hot- or cold-mix pavements.

Life expectancy of double-chip seals on a well-drained, structurally adequate base are reported to be 10 to 12 years, even more than 20 years (Ron Andrus, LCRS Mailing 5, unpublished) provided traffic weight and speeds are not excessive, road alignment is gentle, and if routine seal coats are provided on a regular cycle as described for single-chip seals.

Traditional designs for multiple-chip seals usually call for clean-crushed aggregate screened to single sizes such as ¾ to ⅜ in., ½ in.—#4, and ⅜ in.—#6. The problem is that these gradations are usually quite expensive to manufacture and may not compete well economically with higher-type pavements. To be cost-effective, LCASR designs must take advantage of available local materials and be customized to fit the site conditions.

LIFE CYCLE COSTING

Life cycle costing is a useful technique and should be used to select the most feasible alternatives of construction for LCASRs. The life cycle costs should be based on preliminary designs and cost estimates together with predicted maintenance and operation costs (Milada, LCRS Mailing 4, unpublished). This method provides a convenient way to compare alternative designs including the various costs of constructing, operating, and maintaining them. Operation and maintenance costs are often as critical to a low-volume road agency as initial construction costs.

DESIGN CONSIDERATIONS

Too often, the common practice for selecting an asphalt surface treatment consists mainly of using design information from a previously constructed project. This practice may be expedient and in some cases successful; however, it is frequently the cause of failures or poor-quality surface treatments.

Proper design should include site- and project-specific information on

- Composition, condition, and structural strength of the base or underlying road material;
- Aggregates and asphalt to be used; and
- Environment of the project location.

The structural strength of the road before an asphalt treatment is applied is probably the most influential element in the success of the LCASR. The many methods available to evaluate existing strength are beyond the scope of this paper and it is assumed that a satisfactory method has been used prior to LCASR design.

For strength information, the Forest Service generally performs various field investigations such as deflection testing, sampling, and testing of base and subgrade materials. The field data obtained are then correlated to *Forest Service Handbook 7709.11*, Chapter 50—PAVEMENTS (*4*), which is a primary method used to design aggregate bases, asphalt pavements, and aggregate surfaces.

TYPICAL SURFACING DESIGNS

Following are three proven design methods for asphalt surface treatments that were supplied by contributors to the LCASR study.

Forest Service (California) Design Recommendations

The following procedure is a chip seal design method that can take a large percentage of the guesswork out of determining aggregate and emulsion spread rates (Stephan Johnson, LCRS Mailing 9, unpublished).

The variables in determining spread rates are as follows:

- Void space between the particles in the aggregate (chips),
- Gradation of the aggregate,
- Flatness of the aggregate (flakiness),
- Texture of the surface being chipped,
- Density of the aggregate (bulk specific gravity), and
- Amount of traffic.

There are other factors that have an influence on the success of the job. They include time of the year the job is constructed, and environmental factors such as temperature, humidity, and wind.

The recommended design procedure is contained in Asphalt Institute MS-19 (*2*) which was also published by FHWA (*5*). These publications are virtually identical, but the second edition of MS-19 does not contain the design formulas and accompanying text.

The sieve analysis requires a ¼-in. sieve and the flakiness index requires the use of a gauge or slotted sieves as described in the previously mentioned manual. Flakiness index gauges and sieves can be obtained from engineering and materials testing supply firms.

Plumas and Eldorado National Forest Typical Designs

The following recipes represent the typical practice from Plumas National Forest for constructing a conventional double-chip seal on an aggregate base, and a double-chip seal method developed on the Eldorado National Forest. These include the normal construction sequence, typical material type, quantities used, and other factors affecting cost and performance (Gordon Keller, LCRS Mailing 7, unpublished).

Plumas Double-Chip Seal

1. Subgrade or base (aggregate) should be structurally sound and well drained.
2. Compact base to 95 percent of compaction by the procedures of the AASHTO Test T–180 and obtain a clean, smooth surface.
3. Add penetration treatment—0.40 to 0.50 gal/yd² of MC-250 asphalt for coarse aggregate or 0.35 gal/yd² of MC-70 asphalt for fine aggregate or soils.
4. Let cure 5 to 10 days; blot lightly as needed to accommodate traffic.
5. Apply 0.25 to 0.35 gal/yd² of CRS-2 asphalt.
6. Immediately apply 20 to 30 lb/yd² of ½ in. × No. 4 chips. Uniformly graded chips are best. Also, coarser chips wear longer because they provide more depth, less embedment, and less bleeding, although they require more materials.
7. Roll with pneumatic tire roller.

8. Let cure for 24 (minimum) to 72 hr. The second asphalt and chip application can follow immediately after rolling the first course if strict, complete traffic control can be kept for 24 to 48 hr.
9. Broom off excess chips.
10. Apply 0.20 to 0.25 gal/yd² of CRS-2 asphalt (preferably with latex additive).
11. Immediately apply 15 to 25 lb/yd² of ⅜ in. × No. 6 chips.
12. Roll with pneumatic tire roller followed by steel wheel roller (optional for a smooth surface).
13. Broom off excess chips (optional on low-speed roads).
14. Control traffic speed to 5 to 15 mph for the first 24 hr (4-hr minimum).

Typical asphalt quantity is 0.95 gal/yd² (0.40 gal/yd² penetration application + 0.55 gal/yd²); typical aggregate quantity is 50 lb/yd²; and typical cost is $2.05/yd² (in 1989 dollars). The cost varies with the size and location of project.

With good grade, alignment, and structural conditions, 20 to more than 30 million board feet (mmbf) of timber haul can be expected over double-chip seals, with little damage. Normal conditions will require some patching and maintenance to accommodate this traffic.

Forest Service engineers frequently use millions of board feet to describe haul quantity on roads in areas where timber harvesting is the predominant commercial activity. Extensive harvest records have provided accurate timber volume per loaded log truck (usually estimated to be 5,500 board feet), which weighs about 14 kips per 1,000 board feet (mbf) including the weight of the truck. For structural design purposes, this value equates to about 650 equivalent 18-kip axle repetitions per mmbf. Detailed information and example computations are included in *Forest Service Handbook 7709.11*, Chapter 50 (*4*).

The second course of chips should be one-half the size of the first course.

Large chip seal projects should be designed to consider specific aggregate type, shape, weight, voids, absorption, residual asphalt content, etc.

Weather limitations are important, and warm, dry weather is critical for a successful project. Construction should be before September 15, particularly in northern climates.

Chip seal life is substantially shortened on grades over 12 to 15 percent or if there is tire chain use in winter.

Chip seals are most cost-effective and appropriate on roads with moderate-to-light sustained traffic.

Eldorado Style Chip Seal

1. Provide a ¾-in. aggregate leveling course and additional base aggregate as needed for structural support.
2. Steel wheel (vibratory) roll for compaction and smoothness.
3. Prime with MC-800 asphalt (usually 0.50 gal/yd²).
4. Chip/blot immediately with ⅜-in. chips at 18 to 25 lb/yd². Use ample amount of chips.
5. Roll with pneumatic (rubber tire) roller.
6. Let cure 7 to 10 days.
7. Broom off excess chips.
8. Apply 0.15 to 0.25 gal/yd² of CRS-1 or CRS-2 asphalt with latex additive.
9. Chip again with 18 to 25 lb/yd² of ⅜- or ¼-in. chips.
10. Rubber tire roll again.

Typical asphalt quantity is 0.70 gal/yd²; typical aggregate quantity is 45 lb/yd²; and typical cost is $1.75/yd² (in 1989 dollars).

The Eldorado National Forest has been using this treatment for several years and reports timber haul of 20 to 60 mmbf without damage to the surface. The high performance (over 30 mmbf hauled) may result in part from the treatment being applied to very stable old roads and prompt repair of broken areas. Estimates of timber haul in excess of 30 mmbf can only be expected under ideal conditions.

Less asphalt use and therefore lower cost than a typical double chip seal are advantageous. Chips can be placed immediately on the MC-800 asphalt without a typical penetration treatment which avoids possible contamination of this layer.

This recipe may be improved by using ½-in. chips for the first course and ⅜-in. chips for the second course.

CAUTIONS AND ADVICE FOR CHIP SEALING

There are numerous problems to be considered in the design and construction of a chip seal. Some of the possible problems associated with chip sealing over an aggregate surface follow (Stephan Johnson, unpublished data).

Assumptions

There are two main assumptions that are built into a chip seal design. The first is that the chips are one-sized. A one-sized aggregate as defined by McLeod (*6*), is an aggregate that has a gradation of 60 to 70 percent passing the specified sieve and retained on a sieve having an opening that is 0.7 of the specified size. The second assumption is that the surface receiving the chip seal is hard enough that the aggregate particles are not embedded into the existing surface.

Aggregate Base

This layer together with the subbase, if any, and the subgrade provide the entire structural strength in a typical project that includes a chip seal over aggregate base. No structural strength is considered as derived from the chip seal.

Things that can go wrong include the following:

Chips become embedded in aggregate base. The biggest problem occurs when the aggregate base allows the chip to be partially embedded in the surface of the aggregate and therefore the amount of asphalt material needed to hold the chip in place is reduced. The most obvious cause is that the aggregate base is not adequately compacted.

The aggregate base is out of specifications. The problem is the gradation is not within specifications and allows the chip to be either embedded in the surface or the base is of insufficient strength and shears from torque or centrifugal forces.

Degradation of aggregate base. The quality of the aggregate is poor and it degrades at an accelerated rate.

Inclement weather. If the chip-sealed surface is used during inclement weather and there is not sufficient strength in the aggregate base, the surface will be deformed and probably break up.

Prime

The purposes of the prime are many. The prime preserves the aggregate base in a compact state by maintaining the moisture content, which allows construction and limited public traffic use without causing appreciable damage. The prime penetrates the surface of the aggregate and adds to the total thickness of the asphalt-treated material. Also, the prime provides a surface to which the chip seal will readily adhere. The traditional prime is an MC-70 cut-back asphalt. The asphalt spread rate depends on the porosity or amount of fines at the surface of the aggregate. The moisture content of the aggregate should be optimum and the surface of the aggregate base should be damp just prior to the application of the prime coat.

Things that can go wrong include the following:

- If too much cut-back asphalt is applied and the entire amount does not penetrate, a puddle of residual asphalt remains on the surface of the aggregate base. The end result of these areas is that when the remainder of the chip seal is applied, those areas will be flush with excess asphalt and will probably bleed under traffic.
- If traffic is allowed to use a primed road too soon, the prime may adhere to the tires and cause extensive damage to the treated surface.
- In some areas local air pollution control regulations prevent the use of MC cut-back asphalt. Substitutes that have been used are emulsified asphalt and SC cut-back asphalt. Emulsified asphalt will not penetrate the aggregate surface.
- Another major concern is if insufficient time is allowed before placing the chip seal. If the MC diluent (kerosene) is not allowed to evaporate prior to placing the chip seal, the entire chip seal is softened by the remaining diluent. This is especially true when an SC cut-back asphalt is used because the diluent is usually diesel fuel. Environmental conditions greatly influence the time necessary for the prime to cure.
- Allowing too much time between the prime and the subsequent chip seals may allow existing traffic to cause extensive damage to the prime and, therefore, the surface of the compacted aggregate base.

Asphalt Emulsion/Aggregate (Chip) Seal(s)

Normally, a double-chip seal is applied over an aggregate base. Each subsequent layer uses aggregate one-half the nominal dimension of the proceeding layer. It is also normal procedure to design each size of chips for both aggregate and emulsion spread rates, then add the two oil requirements together and apply 40 percent with the first application of chips and apply the remaining 60 percent with the second application of chips.

The amount of residual asphalt required for a chip seal or seals is based on the average least dimension of the aggregate. The average least dimension is calculated from void space, gradation, and shape of the aggregate. Other factors include kind and amount of traffic and condition of the surface upon which the chip seal is being placed.

Things that can go wrong include the following:

- If any of the factors change from what was used in the chip seal design, the resultant chip seal surface will be affected.
- Other factors that influence the success or failure of the chip seal include cleanness of the chips, time of the year the chip seal is being placed, and how wet or dry the chips are when they are placed.
- The selection of the type of emulsion and any additives such as latex has an effect on the longevity of the chip seal. The emulsions with latex additives are generally considered more forgiving than emulsions without the latex additive.
- The amount of time between the first and second chip seal should not be excessive as the amount of emulsion applied with the first course of aggregate is only 40 percent of the total emulsion requirement and the aggregate is more likely to be displaced by traffic than the finished product.

ENVIRONMENTAL CONSIDERATIONS

Throughout most of the 1980s, an effort has been under way to reduce the amount of hydrocarbons as well as other pollutants in the California air and in other areas that do not comply with state or federal air quality regulations. Some air pollution control districts (frequently part of county organizations) have prohibited the use of certain asphalt cut-backs (asphalt that use volatile cutter stocks). The primary targets have been the rapid cures (RCs) and medium cures (MCs). In some instances, MCs have been allowed for prime coats, in others, no exceptions have been made. Contact should be made with the local air authority before selecting a cut-back asphalt product.

WHAT WAS LEARNED?

The thread that was consistent through a vast majority of the responses was that most LCASRs, to be successful,

1. Need to be applied to a base that is structurally adequate for the expected traffic, and
2. Need to have good drainage.

Other major recommendations are to

- Observe what is working in the geographical area of the proposed project;
- Seek out and consult with local LCASR experts;
- Find out what local materials are available and the costs;
- Customize the designs to take advantage of the local materials, economies, and environment;
- Evaluate the structural strength of the existing base and subgrade [account for traffic—use *Forest Service Handbook 7709.11*, Chapter 50 (*4*)];
- Correct any structural weaknesses with proper drainage, pit run rock, etc. (whatever is appropriate) and make bearing capacity uniform throughout the project;

- Design the LCASR on the basis of the best existing knowledge obtainable—use Asphalt Institute, FHWA, or other pertinent publications, for example, Asphalt Institute MS-14 (*1*) and MS-19 (*2*) for cold mixes, and use the design guides herein for asphalt surface treatments; and
- Be sure to design the aggregate and asphalt quantities on the basis of knowledge of them (i.e., aggregate size, shape, gradation, asphalt grades, etc.).

These techniques exist and do not need to be reinvented, just practiced.

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