An Overview of Alternate Surfacings for Forest Roads

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The use of earth or aggregate surfaces for forest roads has persisted as a result of the low initial cost of crushed aggregates. In recent years, the shortage of crushed aggregates and the long hauls associated with their use have resulted in higher costs for quality aggregates in many parts of the country. The possible use of more economical, unique materials for surfacing forest roads is investigated. A discussion is presented of the necessary background information needed to identify and evaluate the alternate surfacing systems. Guidelines are provided of the applicability of each surfacing system for specific areas and situations. The alternate systems considered include those that are (a) capable of being moved as the hauling or mining activity moves, (b) low-cost materials compared to good-quality aggregates, (c) marginal materials that have relatively short lives but satisfy the project life, and (d) materials that are available in the desired areas to reduce construction costs. A comprehensive market review and literature search, and the construction of demonstration projects were undertaken to evaluate various alternate materials for surfacing forest roads. Potential surfacing types and methods included biodegradable materials (wood and bark chips), chemical stabilization, geotextiles, marginal aggregates, sand-sealed subgrade, metal mats, reusable aggregates, a membrane-encapsulated soil layer, and geoweb stabilization. The results of this research indicate that several of these alternate surfacings can perform satisfactorily and be cost-effective. The most viable alternates include a) wood and bark chips, b) chemical stabilization, c) marginal aggregates, d) reusable aggregates with or without inexpensive geotextiles, e) a sand-sealed membrane, and f) steel mats for emergency situations and short projects.

Of the nation's 3.88 million miles of roads and streets, 1.86 million miles are either unsurfaced or are surfaced only with stone, slag, or gravel (*1*). An additional 1.0 million miles have a minimum surfacing, ranging from surface treatments and chip seals to no more than a 7 in aggregate surface. The U.S. Forest Service operates one of the largest low-volume road networks under the jurisdiction of a single agency in the world. This system contains approximately 330,000 miles of roads of which 92,400 miles have an aggregate surface and 221,000 miles are unsurfaced (*2, 3*). The agency continues to construct and reconstruct 11,000 miles of road annually with an annual expenditure for construction, reconstruction, and maintenance of over $500 million (*2*). Log trucks are one of the major users of these roads. These heavy trucks produce high stresses in the road surfacings; however, the number of repetitions are relatively small. About 90 percent of the roads constructed by the Forest Service are constructed solely for logging traffic that might last a few seasons (or only one) and carry less than 100 vehicles per day (vpd) (*2*).

High-quality aggregate is often not available near the project site, which results in high transport costs. Consequently, the possible use of innovative technology and unique materials for road surfaces was investigated to find more economical surfacing materials. Some of these surfaces could serve a temporary or intermittent use in which the surfacing can be removed and reused again, such as aluminum, steel, and geotextile mats. Other surfaces could be improved by means of soil stabilization, a membrane-enveloped soil layer (MESL), and expandable grids. Finally, some of the surfaces may be economical because of the ready availability of the materials in the desired regions, such as wood, bark chips, and marginal aggregates.

The results are presented of a study sponsored by the USDA Forest Service to identify and evaluate the feasibility of a variety of alternate surfacing systems for use on temporary or intermittent-use roads. The results of a literature study and a field evaluation of 11 demonstration projects are specifically presented in this paper.

POTENTIAL ALTERNATE SURFACING SYSTEMS

A comprehensive literature review and field data collection effort were undertaken to identify various materials and their properties that could be suitable for surfacing temporary and intermittent-use roads. This effort provided the background needed to select the most viable alternate surfacings for use in the field evaluation phase.

Criteria for Alternate Surfacings

The decision of when, where, and under what conditions alternate surfacings should be used is based on traffic conditions, road objectives and needs, subgrade type, materials characteristics, and, most importantly, economics. The following criteria were considered important for defining materials and situations that would be effective applications of alternate surfacings.

Roadway Characteristics

- Temporary or intermittent-use roads,
- Volumes of traffic of 50 to 100 vpd,
- A required surfacing life of 1 to 5 years,
- Short hauling distances from one project to another,
- Poor, low-strength subgrades, and
- Inaccessible or long haul distances.

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Material Characteristics

- Limited or severely restricted supply of good-quality aggregates,
- Materials capable of being moved as logging moves,
- Low-cost materials compared to good-quality materials, and
- Materials available in the project area.

Description of Potential Surfacing Types

A wide variety of alternate surfacing systems were reviewed and investigated to determine their practicality and cost-effectiveness for use on temporary or intermittent-use low-volume roads. The criteria just described were applied to select those materials that had the greatest potential of being effective. A summary of the materials found to have a strong potential for the characteristics of cost-effectiveness, adequate strength, availability, and environmental acceptability is given in Table 1. Each of these surfacing systems is described below.

Biodegradable Materials

Biodegradable materials, including bark and wood chips, sawdust, and planks or logs, have previously been used as road surfacings (*4*). The cost of the wood chip materials ranges from about \$3.00 to \$10.00/yd^3 in-place or \$0.17 to \$0.55/ft^2 for a 12-in surface layer. The wood and bark chips used to construct these roads typically have a size no larger than 6 in. Chips are generally hauled in dump trucks or chipped on site. Compaction from construction equipment is generally sufficient.

Soil Stabilization

Soil stabilization as a technology has been in use for over 50 years. Numerous different stabilizing agents have potential for use in temporary and intermittent-use roads. Lime, lime-fly ash, cement, asphalt emulsions, sodium chloride, magnesium chloride, calcium chloride, and lignin sulfonate have all been used as surfacing systems for low-volume roads. The nature of the subgrade soil is of particular importance in dictating which stabilizing agent should be used.

Marginal (or Degradable) Materials

Marginal materials are those that nearly meet standard American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), or agency specifications for road use. They may require some type of additive or special treatment to perform in the environment in which they are to be used (*5*). Many types of marginal aggregates can be found around the country that can provide satisfactory performance if upgraded. These include, but are not limited to, materials such as cinders, pumice, decomposed sandstone, marginal sand, sand-clay, chert, basalt, and topsoil.

Sand-Sealed Subgrade

The application of an emulsified asphalt on a natural subgrade followed by the application of sand as a topping to waterproof the subgrade soil is called a sand-sealed subgrade (*6*). The sand-sealed subgrade has been used in areas that have a good

TABLE 1 CHARACTERISTICS OF ALTERNATE SURFACING SYSTEMS

Type of Material	General Description	Material Cost	Expected Life
Biodegradable materials (wood or bark chip)	12-24 in of wood or bark chips	\$3-7/yd^3 or \$0.11-0.25/ft^2 [a]	1-3 years
Chemical stabilization	Lime, lime fly ash, portland cement, asphalt emulsion, NaCl, $CaCl_2$, MgCl, lignin sulfonate	\$0.25-0.45/ft^2 [b] (varies greatly with locality)	5-10 years
Geotextile and Geogrid separation	Tensar grids (SSI), various fabrics under crushed rock	\$0.05-0.40/ft^2 plus aggregate	1-3 years
Marginal Aggregate	Single or double layer of sand sealed with CRS-2	\$0.15-0.25/ft^2	3-5 years
Metal mats	Aluminum (AM-2) or steel (M8A1) mats	\$8.33/ft^2 and \$0.90/ft^2 respectively	5-10 years
Reusable aggregate without geotextile separation	6-18 in of crushed aggregate on subgrade	\$0.05-1.10/ft^2 [a] (construct) \$0.20-1.30/ft^2 (recover)	5-10 years
Reusable aggregate with geotextile separation	Fabrics on subgrade with 6-18 in crushed aggregate	\$1.0-1.50/ft^2 [a] (construct) \$.50-1.00/ft^2 (recover)	5-10 years
Membrane encapsulated soil layer	6-24 in subgrade soil encapsulated with various membranes	\$0.50-1.30/ft^2	3-5 years
Geoweb stabilization (expandable grids)	8 in dune sand filled plastic grids, sealed with asphalt	\$1.05-1.30/ft^2 \$1.5-2.0/ft^2 in place	5-10 years

[a]Assumes 12 in surface thickness
[b]Assumes 5% stabilization agent and 6 in depth of stabilized layer

and firm subgrade (CBR greater than 15; R value greater than 40) and that have a plentiful source of low-cost sand compared to crushed aggregate (*6*).

Prefabricated Mat Panels

Landing mats are surface-covering panels that are prefabricated from materials such as aluminum, steel, and fiberglass. The mats come in various panel sizes and can be connected to form a continuous road surfacing. Mats may be effective when temporary surfacings are needed to carry large and heavy trucks or equipment. As a result, they may be applicable for temporary and intermittent-use roads because they can be reused, stored, installed, and removed. Steel mats are not currently being produced but are sometimes available through acquisition of U.S. government surplus equipment (*7*).

Reusable or Recycled Aggregates

The recovery and reuse of good-quality aggregates with or without geotextile as a separation layer may offer an acceptable solution to the shortage of aggregates and high-cost, quality aggregates for temporary or intermittent-use roads. The use of good-quality aggregates with geotextiles and reuse of one or both materials in several projects must account for the properties of materials, availability of materials, performance, and economics.

Membrane-Encapsulated Soil Layer (MESL)

The MESL concept is a method for maintaining the moisture content of the soil at a desired level by encapsulating the soil in a waterproof membrane (*8*). The Waterways Experiment Station developed a method for MESL that consists of first excavating and stockpiling fine-grained soils. Its moisture content is adjusted to 2 to 3 percent below the optimum moisture content for the specified compaction. Following compaction, a CRS-2 asphalt emulsion is sprayed on the subgrade to hold the membrane in place. The excavated soil is replaced and compacted to the desired density and moisture content. An asphalt emulsion is sprayed on the surface and a surface membrane is installed. The top membrane is also sprayed with an asphalt emulsion and covered with a thin layer of clean sand to blot the asphalt and to provide added protection against puncture by construction equipment (*8-10*). Membrane materials used include polyethylene, rubber, vinyl, and polyesters.

Grid Confinement

Grid confinement is a concept for pavement base course construction that was developed at the U.S. Army Corps of Engineers Waterways Experiment Station (*7*). The concept involves the confinement of sand in interconnected cellular elements, called grids, to produce a load-distributing pavement base layer. Poorly graded sands, generally found around the world, can be used in expedient construction of sand-grid base layers for many pavement applications. Three types of grids are available. These include paper grids, aluminum grids, and, most encouragingly, plastic grids (*7, 11*). The plastic grid, called a geoweb, is composed of strips of high-density polypropylene sheets that are spot-welded together on 13-in (33.02-cm) centers (see Figure 1). When the system is expanded, it opens like an egg crate divider into an 8-ft (2.48-m) × 20-ft (6.10-m) panel. The panels are expanded, set in place, and filled with sand. The grids are then compacted and the surface is sprayed with a liquid asphalt. The grid materials currently cost about $1.25/ft^2 of expanded area and the construction costs range from 30 to 60 cents/ft^2 (*11*).

DEMONSTRATION PROJECTS

Eleven demonstration projects were studied to evaluate the construction qualities and performance of the alternate surfacing materials. Six projects were constructed in the summer of 1984. The other five projects had already been constructed. Although most of the projects were in the Pacific Northwest, some were located in the Southeast and Southwest.

Evaluation of the demonstration projects included monitoring the construction, performance, maintenance, and, if necessary, recovery operations. The characteristics of the already existing and new demonstration projects are summarized in Tables 2 and 3.

Demonstration Project Plans

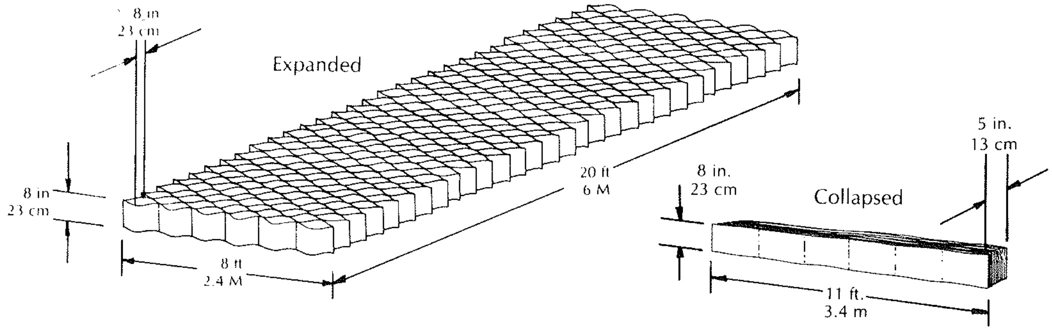
Construction was undertaken with Forest Service maintenance crews for most projects. Materials were obtained through purchase orders. Information collected for both projects included such data as location, general project description, construction requirements, removal and reuse, and estimated costs.

Information collected for project monitoring purposes on each of the projects consisted of a) environmental and traffic data, b) design and construction data, c) maintenance data, d) cost data, and e) performance data. Most of these data were collected using standardized project data sheets. Some of the information had to be estimated, based on interviews with vehicle operators, construction workers, and maintenance personnel. This included qualitative information on the ability of each pavement type to be constructed, to be maintained, and to handle traffic loads.

Results

Wood and Bark Chip Project

This road surfacing consisted of 6-in minus wood chips. Two roads were constructed in late 1981 and surfaced with up to 24 in of chips. Five other roads in the same area were surfaced with aggregate for comparison. The subgrade soil consisted of a clayey silt to sandy silt with an SMu and ML classification, respectively. Prior to construction, 87 percent of the wood chips passed the 6-in sieve and 12 percent passed the No. 4 sieve. Two years after construction, 100 percent passed the 3-in sieve and approximately 84 percent passed the No. 4 sieve. Although the surface was expected to last only for the duration of the timber sale, it was still in good condition as of May 1984. As of May 1984, the ruts were about 2 to 3 in deep. However, traffic was



GEOWEB Structural Properties	English System	Metric System
1. Expanded Dimension	8 ft. x 20 ft. x 8 in.	2.5 m x 6 m x 20 cm
2. Collapsed Dimension	11 ft. x 5 in. x 8 in.	3.4 m x 13 cm x 20 cm
3. Panel Thickness Nominal	0.047 in.	0.119 cm
4. Weight	5.7 lb./yd^2	3.1 kg/m^2
5. Cell Area	41 in.^{2}	265 cm^2
6. Cell Seam Node Pitch	13 in.	33 cm
7. Welds/Seam	7	7
8. Seams Tensile Peel Strength	150 lbs.	69 kg
9. Installation Temperature Range	-16°F to 110°F	-27°C to 43°C

Polymer Material : High Density Polyethylene
Color : Black
Carbon Black Content: 2%
Chemical Resistance : Superior

FIGURE 1 Geoweb confinement system.

light; it consisted of approximately 25 to 30 log trucks and some recreational and administrative traffic. No maintenance was required.

The total cost of construction for two road sections was estimated to be an average of \$0.74/ft^2 for wood chips and \$0.99/ft^2 for crushed aggregate. The wood chips cost approximately \$5.00/yd^3 whereas the aggregate cost about \$15.00/yd^3.

Chemical Stabilization Projects

Several road projects in Region 8 (Southeast) were constructed by mixing lime, cement, bottom ash, or pozzolime with native soils. In some instances, the stabilized soil was used as the wearing surface. In other cases, a thin gravel surface was used.

The surface of the pozzolime-modified soil projects was slippery after rainfall with both sand and clay subgrades, which resulted in a failure of bearing capacity. The pozzolime did not react well with the sand and clay soils initially but gained strength after an additional year of curing and is currently in good condition. On another project, the clay subgrade soil of a road modified with pozzolime and bottom ash performed fairly well until logging operations disrupted drainage and caused saturation of the road bed. A failure in bearing capacity resulted. The road is currently in fair condition. Another road, which consisted of a lime-modified clay subgrade with a gravel surface, developed slick conditions, some potholing, deep rutting, and bearing capacity failures after freeze-thaw conditions. Construction problems may have produced insufficient strength for successful soil modification to take place.

Despite these problems, there were also many successes. For example, a road of pozzolime-modified clay with a gravel surface constructed for a design traffic volume of 7,000 18-kip equivalent axle loads is in excellent condition. The clay soil of another road with a gravel surface was modified with a combination of pozzolime and fly ash and Portland cement and fly ash. The road was built to carry a traffic volume of 2,000 18-kip equivalent axle loads and is also in excellent condition. Finally, a road constructed of Class C fly ash-modified shale gravel base and a surface course that is designed to carry 2,000 18-kip single-axle loads is currently in excellent condition.

The costs ranged from \$0.56/yd^2 to \$4.31/yd^2 for a typical 6-in stabilized layer with an average cost of \$1.74/yd^2, compared to \$2.29/yd^2 for quality aggregate roads.

TABLE 2 EXISTING DEMONSTRATION PROJECTS — SUMMARY TABLE

Project No., Title, Location	Subgrade Soil Type	Surface Type	Cost
Wood and bark chip: Mt. Baker-Snoqualmie NF, WA Region 6 (1981)	Clayey silt to sandy silt SMu to ML	12, 18, and 24 in wood chips	$0.74/ft² [a] avg ($5/yd³)
Chemical Stabilization: Region 8 (1978-1984)	GM, SW, SP, and CH	4-8 in modified subgrade using cement, pozzolime, or fly ash	$0.20/ft² [b]
Geotextile and geogrid separation:[(a)] Olympic,[(b)] Siuslaw, and [(c)] Willamette NF Region 6 (1976, 1983, and 1983)	1. Organic clay and OH-MH 2. Gravelly and sandy SMu 3. Silt-MH	Gravel	$.05-.40/ft² aggregate
Substandard Aggregate: Siuslaw and Willamette NF, OR, Region 6 (1983)	Clayey silt (ML) and sandy silt (SMd)	4-10 in of substandard pit run and crushed rock	$1.15-4.70/yd³ (or $.04-.17/ft²) [a]
Sand Seal: Plumas NF, CA Region 5 (1975)	Clayey silty sand to rocky clay (ML to SM)	Double sand seal	$0.75/ft²

[a]Assumes 12 in surface thickness
[b]Assumes 5 percent stabilizing agent and 6 in depth of stabilized layer

TABLE 3 NEW DEMONSTRATION PROJECTS — SUMMARY

Project No., Title, Location	Subgrade Soil Type	Surface Type	Cost
Geoweb stabilized road: Dunes National Recreational Area - Siuslaw NF, OR Region 6 (1984)	Dune sand (SP)	Sand filled plastic grid 8 in deep	$1.84/ft²
Wood chip roads: Siuslaw NF, OR Region 6 (1984)	Silt to fine sandy silt (ML)	12 in of alder wood chips	$11.17/yd³ or $0.41/ft² [a]
Reused/recycled aggregates: Siuslaw NF, OR Region 6 (1984)	Silt (ML)	Four different fabrics with 8-10 in crushed aggregate	$1.30/ft² [a] to construct and $1.22/ft² [a] for recovery
Metal mat surfaces: Willamette NF, OR Region 6 (1984)	(ML)	Steel and aluminum mats	$8.70/ft² materials and placement, $0.40/ft² recovery
Membrane encapsulated soil Layer: Tahoe NF, CA Region 5 (1984)	Volcanic ash and mud flow mixed with glacial till	6 in subgrade soil encapsulated with membranes with chip seal or 3 in gravel	$0.50-1.28/ft²
Lignin sulfonate soil stabilization: Prescott NF, AZ Region 3 (1984)	Clayey sand (SC) to sandy gravel (GW) - from decomposed granite	4 in of stabilized subgrade covered with a chip seal	$0.25/ft² [b] or $0.68/yd³

[a]Assumes 12 in surface thickness.
[b]Assumes 1.3 percent sulfonate and 4 in depth of stabilized layer.

Geotextile and Geogrid Separation Projects

Projects in three national forests in which geotextiles or geogrids were placed to separate the surface material from the subgrade were investigated. The subgrade soils all had extremely low strengths, which therefore precluded the use of conventional construction practices. These special materials were used to either bridge these weak areas or to reduce the total thickness of the structural section, or both.

One project near Quinault, Washington, was constructed in 1976 using eight different geotextile types and grades (*12*). The subgrade soils were of highly organic clays and silts (Unified classification OH to MH) with a low bearing strength (CBR less than 1). After 2 years of service, the subgrade soil had increased in strength (vane shear) by approximately 250 percent, the moisture content reduced 75 percent (from 218 to 55 percent), and the unit dry weight increased from 78 to 101 pcf. As a result of this gain in strength, the depth of crushed aggregate could theoretically have been reduced from 20 to 10 in. The geotextiles had, on the average, reduced in strip tensile strength to 80 percent of their original values. The average rut depth varied from 0 to 0.37 ft (an average of 0.14 ft), whereas the depths varied from 0.25 to 0.5 ft on the control sections with no fabric. In 1984 the road was in overall good condition; the structural adequacy, and surface and traffic serviceability were at high levels.

The second project was also located in the Northwest. The subgrade soils consisted of gravelly and sandy silts with a classification of SMu and a CBR ranging from 1 to 5. The road was initially constructed in 1980 with 4-oz/yd² Mirafi 500X fabric. The performance and maintenance of the project were impaired in many places because rutting developed during

construction prior to compaction. The first failures occurred between 100 and 300 18-kip equivalent axle loads; ruts greater than 4 in developed. The road was reconstructed in 1983 with a Tensar (SS-1) geogrid subgrade reinforcement.

In the third project, geogrids were used in 9.8-ft widths. Crushed aggregate was then placed over the fabric to an average depth of 12 in that varied from 9 to 17 in. The strength of the subgrade soil increased with time as a result of consolidation by traffic. Within a year, the strength had increased to an average value of 2,240 psf (vane shear), compared to 1,170 psf at the time of construction. Rutting occurred to an average depth of 3 to 4 in; short segments rutted as much as 12 in.

The evaluation of these projects indicated that the use of geotextile separation or reinforcement appears to be an especially good alternative in cases in which the underlying subgrade is of a poor quality or is highly plastic.

Marginal Aggregates

Demonstration projects in two national forests permitted the use of marginal aggregates as a surfacing material to be evaluated. These aggregates, which did not meet such Forest Service specifications as gradation and durability, were placed directly on the subgrade and were expected to be serviceable for 2 to 3 years. Low-quality, crushed aggregates of pit-run and various gradings were used to construct these roads. The aggregates were placed directly on the subgrade soil. The subgrade soil for one project consisted of a clayey silt (ML) or a silty sand (SMd) material with a CBR at 95 percent of T 99 compaction that ranged from 8 to 19. The other project subgrade soil was a clayey silt (ML) with a CBR of 6. A third project had subgrade soils that ranged from silty sand (SMu) to clayey silt (ML) with a CBR around 7. All projects experienced rutting and potholing, including those that did not carry logging traffic.

Comparative construction costs are as follows:

	Cost/ Yd^3		
Material Type	*Project 1*	*Project 2*	*Project 3*
Marginal crushed rock	\$17.00-19.00	\$22.55	\$6.58
Pit-run	—	\$4.69	\$1.15-2.50
Quality crushed aggregate	\$24.50-26.00	\$25.00-28.00	\$11.00-13.00

The economic advantages were reduced or eliminated by the added maintenance costs when the marginal rock was only slightly less expensive than quality crushed rock.

Sand-Seal Project

This demonstration project involved the construction of a sand-seal project and two reconstruction projects. A sand seal was placed directly on the compacted subgrade, which eliminated the need for a prepared subbase or base material. The subgrade soil consisted of a clayey, silty sand to rocky clay from deeply weathered diorite, metagabbro, and serpentine rock. The Unified classification varied from ML to SM; R values ranged from the 20s to 60s, and the CBR ranged from 11 to 19. After about 3 years, half of the surface had failed as a result of either cracking and breaking of the surface or rutting in soft spots. Bleeding of the surface was also a major problem, especially when clean sand was used. Decomposed granite appeared to have enough fines to act as a blotter.

Geoweb-Stabilized Road

This demonstration project tested the use of a three-dimensional plastic grid. Three main problems were identified during construction: (a) an uneven surface as a result of the subgrade preparation, (b) surface leveling of the sand over the top of the grids, and (c) inadequate penetration of the asphalt emulsion. These problems resulted in a lack of bonding of the sand in the top of the grid. Because the loose, unbonded sand on the surface was too deep (2 to 3 in), it failed almost immediately. Traffic was soon avoiding the test section. Because of heavy traffic demands, part of the grid section was torn out and replaced with crushed rock. The loose sand was removed, and 2 to 4 in of crushed rock was placed over the grids on the rest of the section.

The costs of geoweb-stabilized roadways are very high. The cost for this system was \$11.25/yd^2 for the grids and \$5.35/yd^2 for construction and the asphalt emulsion. With experience, the cost could be reduced by approximately 25 percent.

Wood Chip Project

This demonstration project was constructed with 12 in of wood chips that were produced on-site and placed directly over the subgrade for use as a base and surface course. The road section was 200 ft long, the maximum grade was 5 percent, and the expected logging traffic was 1.2 million board feet of timber, or approximately 240 log truck trips. The surfacing material consisted of alder wood chips no larger than 6 in; 100 percent passed a 2-in sieve. The optimum moisture content was around 20 percent, and the maximum density was slightly over 21 pcf. The subgrade soil consisted of silt to fine sand silt (ML classification) with a maximum density of 85.2 pcf and a CBR at 95 percent (ASTM D 698) of 10.0. The cost was \$3.72/yd^2 for the wood chips in the 12-in thick surface.

The Forest Service expected the road to last only for the duration of the timber sale. The only traffic over the roadway has been construction traffic and traffic associated with logging. Speeds over the roadway were generally less than 5 mph. Limited maintenance has been required to repair minor rutting in the surface.

Reusable and Recycled Aggregates

A project to test a reusable and recycled aggregate was undertaken. The project was placed over an ML classification subgrade with a CBR of approximately 5. Four different types and weights of fabric were used to separate the subgrade for the surfacing aggregate, including Exxon GTF-400E, Mirafi 600X, Mirafi HP1200, and Fibretex 400R. Between 8 and 10 in of crushed aggregate were placed on top of the fabric as a base and wearing surface. The aggregate had a USFS grading of "G"; 100 percent passed the 2-in sieve and 4.3 percent passed the No. 200 sieve (*13*).

Aggregate from the project was recovered in late August of 1984. The aggregate was first scraped using a JD 450 bulldozer to within 3 in of the geotextile surface. The recovery operation was extremely difficult and slow because of the rutting and

uneven subgrade. In some cases, the bulldozer damaged the geotextile in spots in which the aggregate thickness was only 1 in. The edge of the geotextile was then exposed using shovels. A recovery beam was then sewn to 3 ft of the edge of the exposed fabric. Cables with turnbuckles were attached to the beam, and the other end was attached to the front-end loader (see Figure 2). Finally, the fabric was pulled back by the loader and cables, rolling the aggregate into a cylindrical pile. The aggregate pile was then loaded into trucks and the fabric was salvaged. Some tearing of the fabric occurred in all sections.

Construction of the section cost about $11.70/yd^2 and 90 percent of the 277 tons of aggregate placed were recovered and reused. It is expected that the production rate could have been nearly doubled if only the aggregate was recovered. The net savings associated with the recovery operation as a result of the value of the recovered materials is about $5.67/yd^2. Thus, the net recovery cost was about $6.03/yd^2. The project probably would have been more economical if an inexpensive fabric had been used and only the aggregate had been recovered.

FIGURE 2 Attaching and pulling the recovery system.

Metal Mat Surfaces

This project tested the use of metal mats as a wearing surface placed directly on the subgrade. The project was constructed in 1984 and was surfaced with both steel and aluminum mats that were 12 ft wide. No special problems were encountered when the mats were laid other than the occasional need to bend some of the tongues on the steel mats so that they aligned properly.

Because the steel mats are no longer manufactured, only the 1960 cost of $0.90/ft^2 is available. Current 1987 costs for the aluminum mats are $9.18/ft^2 for quantities less than 30,000 ft^2, and $8.33/ft^2 for quantities over 30,000 ft^2. Hauling, equipment, placement costs, and subgrade preparation will add approximately $0.20 to $0.40/ft^2 to this cost. Recovery costs are approximately $0.40/ft^2.

The steel mats rutted under traffic and separated at two locations. Some of the rutted panels are unusable. The performance of the aluminum mats was excellent.

Membrane-Encapsulated Soil Layer (MESL)

This project tested the use of plastic and fabric membranes to encapsulate a layer of subgrade soil. The plan was to encapsulate a 6- to 8-in lift of subgrade soil with various types of membrane fabric. Three different types of membrane material were used: a 6-mm black polyethylene film, a 20-mm nonwoven geotextile (Fibretex), and a 36-mm reinforced chlorinated polyethylene (RCP). A CRS-2 emulsion was used to tack the various membranes together and bind the chip seals. A 3/8-in crushed rock was used for the chip seal and a 1/2-in crushed rock was used for a surface rock layer.

The 6-mm polyethylene material was unsuitable for the project. It had no tensile strength, and tore and punctured easily. In addition, the asphalt emulsion and chips did not adhere to it when it was used as the top layer of the encapsulation. In fact, as a result of recreational and timber haul traffic during the first month of operation, the chips tore the membrane severely and the wearing surface was therefore lost. The other two materials, the geotextile and the RCP, performed acceptably.

The membrane materials cost $0.56/ft^2 for the 36-mm reinforced polyethylene, $0.051/ft^2 for the 20-mm Fibretex geotextile, and $0.029/ft^2 for the 6-mm polyethylene. The construction cost, including equipment, labor, and materials was as follows:

36 mil material: $11.52/yd^2
6 mil material: $ 4.60/yd^2
20 mil material: $ 4.50/yd^2

Lignin Sulfonate Soil Stabilization

The use of lignin sulfonate, a by-product of the pulp and paper industry, as a stabilizer for subgrade soil was tested on this demonstration project. The project was constructed in 1984 using the lignin to stabilize a subgrade soil that was subsequently covered with a chip seal for a wearing surface.

At least three types of lignin sulfonate are available on the market and in use as soil stabilizing agents or dust abatements: ammonium lignin sulfonate, calcium lignin sulfonate, and sodium lignin sulfonate. Calcium lignin sulfonate was used as a stabilizer in this project. It was the least expensive type and no conclusive evidence was found to indicate that it would perform much differently than the other types. The subgrade for the project varied from a clayey sand (SC) to a sandy gravel (GW) soil derived from decomposed granite.

The project has performed very well to date and no problems have been experienced. It has provided good traction and bearing capacity and has had a relatively smooth, high-quality riding surface. The costs of construction were $1.20/yd^2 for lignin stabilization and $1.10/yd^2 for the chip seal, for a total of $2.30/yd^2.

EVALUATION OF PROJECT RESULTS

The suitability of a particular surfacing system depends on environmental and economic factors, subgrade, unique requirements for construction and maintenance, limitations on its use, and projected loading conditions.

About half of the alternate surfacings evaluated required special technology, equipment, or expertise to construct and maintain. These requirements are summarized in Table 4.

Some of the alternate surfacings that were properly constructed and maintained performed adequately. Specific aspects

TABLE 4 UNIQUE REQUIREMENTS OF THE ALTERNATE SURFACING SYSTEMS

Potential Surfacing Types	Construction, Recovery, and Maintenance Technology	Special Equipment
Wood and bark chip	The same as aggregate roads	Chipper
Chemical stabilization	Special construction methods necessary special expertise in mixing and spreading	Pulva-mixer or twin disk harrow, distributor tanker
Geotextile or geogrid separation	Special construction methods necessary	None required
Marginal aggregate	None required	None required
Sand-sealed subgrade	None required	None required
Metal mats	None, mats easily pieced together in field	Forklift or truck-mounted crane, pressure washer, mobile welder
Reusable aggregate without geotextile separation	None required	None required
Reusable aggregate with geotextile separation	Requires special technology for the recovery of materials	Sewing machine, recovery system
Geoweb stabilization (expandable grids)	Technology requires special knowledge for geoweb placement, filling, leveling, and compaction	None required
Membrane encapsulated soil layer	Technology is unique in laying fabric, applying emulsion, compacting, and sealing joints	Asphalt sprayer

of these surfacing materials are discussed in Table 5. The potential applications of these materials are described in Table 6.

CONCLUSIONS AND RECOMMENDATIONS

The results of the study indicate that alternate surfacings can be used in many situations. Based on the total cost of construction and maintenance and the limited performance data, the most promising surfaces, in no particular order, for typical logging roads are as follows:

- Wood and bark chips,
- Chemical stabilization,
- Marginal aggregates,
- Reusable aggregates with or without inexpensive geotextiles,
- Sand-seal membrane, and
- Steel mats for emergency situations and short projects.

The characteristics of the log haul, the subgrade, and the availability of materials dictate which materials are most cost-effective.

Conclusions

The following specific conclusions can be drawn from this study:

- Biodegradable materials, such as bark and wood chips, can perform suitably on temporary roads, especially logging roads, because they are inexpensive and available. These materials are recommended for short roads (less than 1 mi) with low speeds and moderate grades.
- Admixture stabilization materials, such as lime, Portland cement, emulsified asphalt, fly ash, sodium chloride, calcium chloride, magnesium chloride, and lignin sulfonate, can be used to upgrade local soils and marginal aggregates. The selection of specific additives to stabilize the materials depends on the

TABLE 5 PERFORMANCE AND ECONOMIC EFFECTIVENESS OF ALTERNATE SURFACINGS

Material	Performance	Economic Effectiveness
Biodegradable materials	Limited rutting, low dusting levels	Economic, easily constructed
Chemical stabilization	Some bearing failures, limited rutting and potholing	Very economic
Geotextile, geogrid separation	Some rutting, strength increase under fabric	Geotextile economic; geogrid too costly
Marginal aggregate	Differs by subgrade soil and material; early rutting possible	Low construction costs, but high maintenance costs possible
Geoweb Stabilization	Half of surface cracked, potholed, rutted after 3 years; surface bleeding prevalent	Cost effective in certain locations
Reusable/Recycled aggregate with geotextile	Performs as well as quality aggregate	Economically effective if light textile used, but not recovered
Metal mat surface	Slippery when wet; panels and connectors bend with use on poor subgrade	Materials costs very high; economically effective for bridging wet or soft spots
Membrane encapsulated Soil layers	Controls frost heave; maintains strength; controls moisture content	Cost effective for poor, moisture sensitive soils

TABLE 6 POTENTIAL APPLICATIONS OF THE ALTERNATE SURFACING SYSTEMS

Potential Surfacing Type	Potential for Future Use[a]	Applicable Situation
Wood and bark chips	High	Subgrades with wood and bark chips available
Chemical stabilization	High	Depends on soil type; clayey soils best
Geotextile or geogrid separation	High	Weak, wet, and fine-grained subgrades
Sand- or chip-sealed subgrade	Low	May not work on weak subgrades (CBR <15)
Metal Mats	Low (Alum.) Medium (Steel)	Economical only on short sections
Reusable aggregate without geotextile separation	Medium	Firmer subgrade to control rutting and intrusion of fine material
Reusable aggregate with geotextile separation	Medium	Soft low strength subgrades, may increase in strength
Membrane encapsulated Soil Layer	Low	Economical only on short critical sections
Geoweb stabilization	Low	Uniform sands and critical sections
Lignin sulfonate soil stabilization	High	Dry climates, requires a surface seal

[a]High: up to 80 percent of USFS local mileage; medium: up to 50 percent of USFS local mileage; low: less than 10 percent of USFS local mileage.

subgrade material types and the availability and costs of the additives in the area. Many such projects have been constructed on temporary and intermittent-use roads. This is likely to be one of the most economical solutions.

- Marginal aggregates are widely available and have a low initial cost. They are recommended for use on roads with short project lives (1 to 3 yrs).
- Conventional geotextiles and extruded plastic grids can be used to stabilize weak soils. They are recommended for situations in which rock is costly because they reduce the amount of rock required.
- Sand-sealed subgrades are recommended for sections that have a good, firm subgrade (CBR greater than 15; R value greater than 40). The soft nature of the sand seal probably precludes its use on steep grades or sections with sharp curves. Therefore, the use of this material should be limited to roads with firm subgrades, moderate grades, and a short project life (1 to 3 yrs).
- Steel and aluminum mats are recommended for use on short sections of road or for emergency situations because of their high initial cost.
- The recovery and reuse of good-quality aggregates separated with a layer of geotextile may not be economical because of the high cost of the geotextile. The recovery and reuse of good-quality aggregates without a layer of geotextile may reduce construction costs. It is expected that about 70 to 75 percent of the aggregates could be recovered each time.
- The membrane-encapsulated soil layer (MESL) concept should only be considered for use in regions with very fine-grained soils, a high moisture content, and a lack of quality aggregate.
- Geowebs are not economical for temporary or intermittent-use roads when compared to crushed aggregates because of the high initial cost of materials.

Recommendations

Much work remains to be done before the economic feasibility of alternate surfacings can be completely understood. This study was based on a summary of existing literature and the construction and evaluation of 11 demonstration projects in which various alternate surfacings were tested. No conclusions should be drawn from the results of this study that would lead to the application of these materials across the entire country without first determining their suitability. Additional study of these materials in low-volume, temporary, or intermittent-use road applications would be of tremendous value.

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REFERENCES

1. M. C. Everitt. *A Discussion of Aggregate Properties for Untreated Road Surfaces.* USDA Forest Service, Rocky Mountain Region, Dec. 1981.
2. J. E. Hernandez, B. F. McCullough, and W. R. Hudson. A Data Base of the U.S. Forest Service Pavement Management System. *Transportation Research Report 66.* Center for Transportation Research, University of Texas, May 1981.
3. M. R. Howlett. *Special Report 160: Managing a 200,000-Mile Road System: Opportunity and Challenge.* TRB, National Research Council, Washington, D.C., 1975.
4. K. G. Buss. *Use of Sawdust on Forest Roads.* Technical paper presented at Road Builder's Clinic, Moscow, Idaho, March 1984.
5. N. S. Shah, K. P. George, and J. S. Rao. Promising Marginal Aggregates for Low-Volume Roads. In *Transportation Research Record 898,* TRB, National Research Council, Washington, D.C., 1983.

6. Compendium of Demonstration Projects for USDA Forest Service Project on Alternate Surfacings. *Transportation Research Report 85-2.* Transportation Research Institute, Oregon State University, Corvallis, Feb. 1985.
7. G. L. Carr, H. L. Green, and H. M. Taylor, Jr. *Tactical Bridge Access/Egress—Preliminary Investigation.* Geotechnical Laboratory, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Miss., Sept. 1980.
8. N. Smith. Construction and Performance of Membrane-Encapsulated Soil Layer in Alaska. *CRRL Report 76-16.* U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, N.H., June 1979.
9. J. M. Sayward. Evaluation of MESL Membrane—Puncture, Stiffness, Temperature, Solvents. *CRRL Report 76-22.* U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, N.H., June 1976.
10. R. A. Eaton and R. L. Berg. New Hampshire Field Studies of Membrane-Encapsulated Soil Layers with Additives. *Special Report 80-33.* U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory, Hanover, N.H., Aug. 1980.
11. *Geoweb Grid Confinement System.* Presto Products, Inc., Industrial Division, Appleton, Wisc., 1981.
12. J. Steward, R. Williamson, and J. Mohney. *Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads.* Report FHWA-TS-78-205. U.S. Forest Service and FHWA, U.S. Department of Transportation, June 1977.
13. *U.S. Forest Service Standard Specifications for Construction of Roads and Bridges.* Report EM-7720-100. U.S. Department of Agriculture Forest Service, Washington, D.C., 1979.

Evaluation of Alternate Surfacings for Forest Roads

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A procedure is presented to evaluate potential alternate surfacings for forest roads and to compare their cost-effectiveness with crushed aggregate road surfacings. The alternate surfacing types considered include (a) biodegradable materials (wood and bark chips), (b) chemical stabilization, (c) geotextiles, (d) marginal aggregates, (e) sand-sealed subgrade, (f) metal mats, (g) reusable aggregates, (h) membrane-encapsulated soil layer, and (i) geoweb stabilization. The use of the alternate surfacings presents an attractive alternative when compared to the use of crushed aggregates from the standpoint of a savings in aggregate, utilization of the waste materials, and most important, cost-effectiveness. A two-step evaluation procedure was developed and recommended to evaluate the alternate surfacing types. The preliminary evaluation step is to screen various alternative materials based on their characteristics, limitations, and availability. Those materials that have the strongest potential to be effective are identified. The next step is to evaluate the cost-effectiveness of these alternate surfacings to determine which materials have the least total present worth of life-cycle costs. This methodology is applied to two examples of low-volume logging roads. The sensitivity of the decision of which material is most suitable is demonstrated by important variables and costs. Finally, a user-friendly computer program that demonstrates the evaluation methodology is proposed to aid in the decision-making process of whether to use aggregate or alternate surface to build a road.

The USDA Forest Service, Bureau of Land Management (BLM), and other agencies or industries traditionally place crushed rock, pit run, or select borrow material on intermittent-use or temporary-service roads when a surface is warranted to haul timber or for other resource activities. When the timber haul, mining, or other activities are completed, the surfacing and the capital investment that these activities represent lie idle for periods of up to 20 years. A description is provided of the evaluation of selected alternate surfacing systems that can reduce the total investment in intermittent-use and temporary-service roads. For more information on this topic, refer to "An Overview of Alternate Surfacings for Forest Roads," by M. B. Takallou et al., which can be found elsewhere in this publication. The alternatives considered include surfacing systems that are capable of being moved as the hauling, mining, or other activities move; degrade soon after use; significantly reduce the amount of surfacing required; or make better use of available resources to reduce construction costs.

The overall purpose of this study is to provide the background to evaluate alternate surfacing systems and compare their cost-effectiveness with that of quality aggregate-surfaced roads. The methodology used to analyze and evaluate the effectiveness and economic viability of potential surfacing systems is described.

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