Use of Woodwaste for Road Construction in Southeast Alaska

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Wood fibers have a long history of use in road construction across the United States and British Columbia. They have been used in highway and low-volume road construction to reduce landslide potential and to cross settlement-sensitive areas. The USDA Forest Service has used wood fibers in many forms as an embankment material and as an alternative surfacing material. Many forms of wood fibers may be used in construction, including brush, construction slash, chunkwood, and sawmill residue such as bark, sawdust, and planer shavings. The history of wood fiber use is discussed and a recent USDA Forest Service demonstration project that used sawmill-generated woodwaste to construct 4 km (2.8 mi) of forest access road in Wrangell, Alaska, is outlined. The project was implemented to study the suitability of these materials for use in southeast Alaska. An evaluation of the engineering performance characteristics was conducted in an effort to determine some guidelines for future use. This evaluation focused on the rutting potential and road stiffness. A series of field and laboratory tests was conducted to address these issues. The main findings of the study are that the wood fibers perform adequately as both a driving surface and as a base layer for aggregate surfacing materials such as crushed or shot rock. When wood fibers are used as a driving surface, routine maintenance must be done to correct rutting and low-frequency washboarding. Blading may be done easily with a standard motor grader or a bulldozer.

Wood fibers have been used for a long time as a road building material in southeast Alaska. The use of logs and brush as a cover over organic soils and muskegs increased with the use of hydraulic-operated backhoe excavators in the late 1970s and early 1980s (*1*). Most logging roads constructed for the USDA Forest Service or other logging operators are constructed using a wood "debris mat." Most forest roads in southeast Alaska are first excavated to "pioneer grade," which is 60 cm (2 ft) below the designed subgrade elevation. This excavation usually occurs on side slopes and through cuts and can extend from 0 to 4 m (0 to 12 ft) deep at the road centerline. The excavated soil and rock are used to construct a bench, usually 7 to 8 m (20 to 25 ft) wide, upon which nonmerchantable trees, brush, limbs, and other construction slash are placed to form the debris mat. Blasted quarry rock is then placed by end dumping and spreading with a bulldozer to the designated subgrade elevation. A vibratory grid roller and motor grader may be used to finish the road surface or the road may be surfaced with crushed aggregate.

A number of experimental projects have used sawmill-generated woodwaste, including sawdust, bark, and shavings as a lightweight fill material. In the early 1970s, the state of Washington constructed a sawdust fill across a landslide area (*2*). In the 1960s and 1970s, British Columbia officials used wood fibers in three projects to cross settlement-sensitive areas such as peat and sensitive clay soils (*3*). In the 1980s, a number of roads were constructed over peat bogs in northern Minnesota and in northern Wisconsin using sawmill-generated woodwastes, wood chips, and chunkwood (*4*). Chunkwood is a large blocky material that is manufactured on site using a prototype chunker machine developed by the USDA Forest Service (*5*). Wood chips are a small, thin material that can also be produced on site with a chipper. Field observations indicated that chunkwood had better potential for road building than sawmill woodwastes or wood chips. The chunkwood seemed to have less compressibility than the other materials and seemed to hold up much better under traffic when there was no gravel cover material. With a gravel cover over the wood particles, there seemed to be little difference in the behavior and suitability of the various materials.

The wood chip fills that were constructed in 1983 in northern Minnesota and Wisconsin are still functioning as designed. The wood chip fill seems intact and can still carry normal traffic. It has not settled into the weak muskeg soils and still appears to be highly permeable. In 1986 it was suggested that chunkwood would make a better road than wood chips. Chunkwood and wood chips were comparable in cost to produce.

It was recognized that before wood particles, such as sawmill woodwaste, chunkwood, and wood chips, would be accepted as an engineered road construction material, further testing of the mechanical properties of wood particles was needed. A contract was awarded to Michigan Technological University to conduct a series of laboratory and field tests on the engineering properties of chunkwood (*6*). Field tests indicated that chunkwood did not compact excessively under traffic. Maintenance was minimized where the traffic had enough road width to off-track rather than follow the same path with each pass. The rut depth tended to accumulate to about a 76-mm (3-in.) depth after 20 to 30 passes of a loaded truck with mounds of 51 to 76 mm (2 to 3 in.) high accumulating parallel to the ruts. The maximum measured rut depth after 200 passes of loaded trucks was about 18 cm (7 in.). The ruts were corrected by allowing the trucks to off-track for seven or eight additional passes. The use of a geotextile and the addition of sand or gravel to the surface of the chunkwood greatly increased the stiffness of the roads. It was observed that just enough sand to fill the chunkwood voids would provide the best roadway (*7*).

Laboratory tests were conducted on the chunkwood material. The tests indicated that a permeability of 0.4 km/hr (20 ft/min) should be expected, with a maximum of about 2 km/hr (120 ft/min) (*6*). Field observations confirmed that the material had a very high degree of permeability. Laboratory tests also showed that chunkwood was weaker when the moisture content was high (*7*) and was variable with wood species. A reasonable estimate for future design is a compacted moist unit weight of 640 kg/m^3 (40 lb/ft^3). The Mohr-Coulomb strength law was found to be valid with a cohesion intercept of 14 kPa (2 psi) and an angle of friction of 37 degrees (*6*).

Chunkwood roads have also been constructed in Mississippi, Louisiana, Oregon, Alaska, and several locations in British Columbia, Canada (*5,8*). The major problem with using chunkwood as a road building material is in the production of the chunkwood material. Unfortunately, the woodchunker was developed as a prototype, not as a production machine. To further develop the potential of chunkwood roads, a first-generation production machine will have to be built.

Nemo Point

The Nemo Point demonstration project was implemented because of a number of factors. One factor was the availability of suitable blasted rock borrow and the high cost of hauling when suitable sources could not be found near the project area. Most roads require a depth of 61 to 122 cm (2 to 4 ft) of blasted rock borrow, which combined with hauling is the most expensive component of road construction. Even when rock sources are readily available in the area, road construction costs can be quite high. The cost of single-lane road construction in Alaska is $86,956 to $111,801 per km ($140,000 to $180,000 per mile), not including major culverts or bridges. This combined with industry's need to dispose of large quantities of sawmill-generated woodwaste provided an opportunity to study the cost-effectiveness and the suitability of these materials for road construction.

A cooperative agreement was made between the USDA Forest Service and the Alaska Pulp Corporation sawmill in Wrangell, Alaska, to construct the 4-km (2.8-mi) Nemo Point demonstration project. Support for the project was to be received from the Alaska Department of Environmental Conservation provided that a water-quality monitoring program was included.

Several large-capacity end dump trucks were used to haul the material to staging areas as construction progressed. Smaller trucks, 8 m^3 (10 yd^3) in capacity, were used to move the material to the construction heading. The material was spread with a Caterpillar D7G bulldozer. Two staging areas were used to stockpile material on site: one was at the beginning of the project; the other 1 km (0.5 miles) from the beginning.

Layer construction was used on the project. Woodwaste fills were constructed in lifts of approximately 51 cm (20 in.). As construction progressed, additional compaction of the layers was achieved through the dump truck traffic. Figure 1 shows the wood fiber embankment before surfacing. Once the road was constructed to subgrade, the aggregate surfacing was placed. For the nontest section areas, a 61-cm (2-ft) depth of shot rock was placed followed by a driving surface of 10 cm (4 in.) of crushed aggregate. Figure 2 shows a typical cross section of the road. Figure 3 shows the finished road.

One of the major construction problems was the lack of compaction on the outside edge of the embankments. Equipment working on the outside edge caused failures, the result of which was that the equipment rolled down the oversteep (1:1) fill slopes. The material naturally stood in a 3/4:1 slope. By layer compacting, a fill slope between 1:1 and $1^1/_4$:1 was achieved.

Engineering Performance Study

The purpose of this study was to determine the engineering performance characteristics of sawmill-generated woodwaste and to establish some general design guidelines for future use. The study was based on the field performance and a laboratory evaluation of the material.

Field Performance

Experiment Design

The field study was designed to evaluate the performance characteristics of the sawmill-generated woodwaste material under various subgrade conditions and surface types. The main emphasis was on the road stiffness and rutting potential. The road stiffness was de-

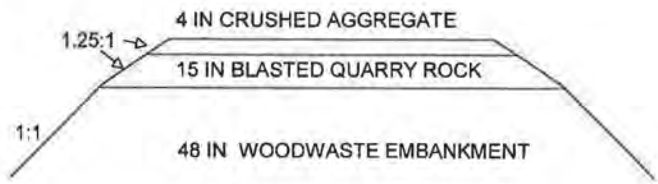

FIGURE 2 Typical cross section of nontest site.

termined using a falling weight deflectometer (FWD) to measure surface deflections. The rutting potential was determined by measuring rut depths after various numbers of truck passes over each section.

Test Section Design

The test sections were designed using a matrix approach to incorporate two thicknesses of woodwaste and two thicknesses of both shot rock and crushed aggregate surfacing. This approach was used for muskeg and non-muskeg subgrade conditions. Table 1 shows the matrix for the two subgrade conditions in combination with the treatments applied to the test sections.

A geotextile was used on half of each test section and was placed between the woodwaste and the aggregate surfacing. Figure 4 shows a typical cross section of the test sites using the geotextile. The geotextile was placed to study the effects on road stiffness and rutting of having a separation layer. The fabric used was a Nicolan style 1120N, a 100 percent polypropylene, nonwoven, needle-punched fabric.

Rutting Potential

For each section, rut measurements were taken on the woodwaste before surfacing. The rutting measurements

FIGURE 1 Unsurfaced woodwaste road.

FIGURE 3 Finished woodwaste road.

TABLE 1 Test Section Design Matrix

WOODWASTE - MUSKEG SUBGRADE CONDITIONS		
AGGREGREGATE	THIN SECTION(30")	THICK SECTIONS(48")
CRUSHED		
THIN(6")	#6	#7
THICK(12")	#5	Future
SHOT ROCK		
THIN(15")	#2	Future
THICK(24")	Future	Future
WOODWASTE - NON-MUSKEG SUBGRADE CONDITIONS		
AGGREGREGATE	THIN SECTION(30")	THICK SECTIONS(48")
CRUSHED		
THIN(6")	#3	Future
THICK(12")		
SHOT ROCK		
THIN(15")	#4	#1
THICK(24")		

on the unsurfaced woodwaste give an indication of the rutting potential of the material. The goal of the rutting study is to correlate rut depth to 80-kN (18-kip) equivalent single axle loads (ESALs).

Rut depths were calculated by measuring the transverse surface profile in relation to a predefined datum. The first measurement is a control that measures the profile in the unrutted condition after blading of the surface. Additional data were collected after various round trips of the dump trucks. The number of round-trip truck passes were converted to an 80-kN (18-kip) ESAL using a USDA Forest Service system based on axle weights and tire pressure (*9*).

Road Stiffness

A Dynatest FWD supplied by the Alaska Department of Transportation was used to measure surface deflections in the test sections. The FWD arrived on site set up for standard pavement applications. Because of the nature of the material and several problems encountered during testing, it was necessary to adjust the loads and drop height to generate accurate information. These problems were a bounce-back or drift effect that caused a vibration in the sensors, and the accurate range of the sensors was insufficient with higher loads. A load of approximately 12 kN (2,600 lbf) was determined to be the highest possible load that would generate accurate data. To achieve these low loadings, it was necessary to reduce the weight configuration to the lowest level and vary the drop height to adjust the final loads at the road surface. Because of the uneven nature of gravel surfaces, sensor location is very important. At many points along the road, a very thin film of sand was required to level the area under the load plate and around the sensors. If the sensors are on a rock or in a depression, the readings are not accurate.

Discussion of Results

General Observations

Before it was surfaced with aggregate, the woodwaste material performed adequately as a driving surface for the construction traffic on the project. It provided a very

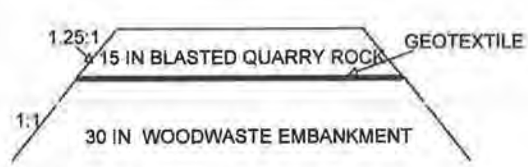

FIGURE 4 Typical cross section of test site with geotextile.

quiet and soft ride as well as good traction for administrative traffic such as pickups and Suburbans.

A woodwaste material depth of 46 cm (18 in.) was able to carry construction traffic in the muskeg areas, but did not seem to provide a significantly stable base for extended use or for supporting a surface layer. Depths greater than 61 cm (24 in.) performed well.

The woodwaste surface tended to produce a low-frequency washboard effect in certain areas. These areas were on grades greater than 12 percent and on either side of any hard spots in the road. The washboard on steep grades seemed to be caused by the driver's need to brake in the favorable direction. The other problem area was around culvert installations and along areas of solid rock excavation. Because these areas are significantly more rigid than solid woodwaste fills, they cause traffic to bounce and they produce washboarding.

The woodwaste material compacts well under construction equipment, but very little compaction occurs in the top 4 to 6 in. This layer seems to stay in a "fluffy" condition and floats over the surface under the influence of the truck traffic. This characteristic is very important in considering the rutting potential of the wood fibers without a surface material. One benefit of this characteristic is that it allows the material to be self-healing if drivers vary the wheel paths between trips.

The types of woodwaste materials used in the embankment made significant differences in the results of the analysis, especially the rutting potential of the woodwaste material. Three types of woodwaste materials were used: sawdust, planer chips, and bark fibers. Each of these materials behaves differently. Sawdust does not seem to perform as well as the other fibers. Its particles are very small and tend to break down under traffic loading. When it is predominant in the section, deeper rutting tends to occur. Planer chips do not compact very well. These are very thin fibers of various shapes and sizes that tend to resist compaction. Bark fibers are long thin fibers that intertwine and form a well-compacted layer. The woodwaste material seemed to perform the best when placed with a good mixture of particle types.

Rutting Results

The objective of the analysis was to determine the relationship, if any, between the rut depth and 80-kN (18-kip) ESALs. Simple linear regression was used to obtain the results presented below.

The regression analysis determined the relationship between rut depth and ESALs to be rut depth = 1.749 + 0.012*(ESALs), with a resulting two-sided p-value of 0.00107. The standard errors for the intercept and slope are 0.197 and 0.0035, respectively. The 95 percent confidence interval for the slope parameter is 0.00524 to 0.0195. The small p-value shows evidence of an association between these variables. A lack-of-fit analysis also suggests a relationship between the variables (p-value = 0.534).

Although the results of the analysis suggest that there is an association between the variables, only a small percentage of the variation is accounted for by the independent variable ESALs, $R^2 = 21.79$. For this type of application, it may be enough to adequately design for rutting. However, there are several factors that may account for additional variability. These are the moisture content of the material, the type of wood fibers that make up a majority of the test section, and the fluffy nature of the top few inches of the unsurfaced layer. Further analysis should be done on the surfaced woodwaste to determine how the various surface materials affect the rutting potential.

Road Stiffness Results

The FWD data were used to evaluate the resilient modulus of the woodwaste layer. The deflections for each test point were normalized to a loading of 9 kN (2,000 lbf) and were analyzed using the computer program Bousdef 2 (*10*). A statistical analysis of the data was done using a one-way analysis of variance.

The average resilient modulus for all points was 14 kPa (2,041 psi) with a standard error of 1 kPa (189 psi). Several variables were analyzed for their effect on the stiffness of the woodwaste layer. An analysis of variance was done to compare modulus values with respect to woodwaste depth, aggregate surface depth, the use of a geotextile, and the subgrade type.

The first test compared the modulus values according to the depth of the woodwaste layer. This test shows no statistical difference in the mean modulus values of the two groups (p-value = 0.3537). The second analysis compared the modulus values according to the depth of surface aggregate. Three surface depths were used on the project: 15 cm (6 in.) and 30 cm (12 in.) of crushed aggregate and 38 cm (15 in.) of shot rock. The test shows a statistical difference between the groups (p-value = 0.00). A comparison of the use of geotextile shows no statistical difference between the fabric and no fabric groups. Many types of geotextiles are available on the market. A difference type of fabric may produce a different effect on the stiffness of the layer. Table 2 shows the results of these tests.

The analysis of variance shows that the aggregate surface thickness has the most potential influence on the stiffness of the woodwaste layer. The thicker surfaces yielded higher average wood-layer modulus values. The thicker surface layers appear to control the deflections, producing lower deflections and yielding higher resilient modulus values for the woodwaste layer. Part of the

TABLE 2 Analysis of Variance Test Results for FWD Deflection Data

WOODWASTE DEPTH	0.76 m (30 in.)	1.22 m (48 in.)	
MEAN	14.9 KPa (2162 psi)	12.2 KPa (1769 psi)	
STANDARD ERROR	1.67 KPa (243 psi)	1.90 KPa (276 psi)	
AGGREGATE DEPTH	**0.15 m (6 in.)**	**0.305 m (12 in.)**	**4.6 cm (15 in.)**
MEAN	9.05 KPa (1313 psi)	25.09 KPa (3642 psi)	15.25 KPa (2214 psi)
STANDARD ERROR	1.17 KPa (170 psi)	3.84 KPa (558 psi)	1.46 KPa (212 psi)
GEOTEXTILE USE	**GEOTEXTILE**	**NO GEOTEXTILE**	
MEAN	16 MPa (2294 psi)	12 MPa (1774 psi)	
STANDARD ERROR	2 MPa (300 psi)	1MPa (216 psi)	

reason for this is that the thicker layers produce a higher static load, compressing the woodwaste and causing it to become more stiff. The difference between the crushed and shot rock surfaces is likely because of the material gradation. The denser gradation of the crushed aggregate provides better particle interlock, allowing the surface to spread the load over a wide area. The shot rock contains a large volume of voids and consists of predominantly large particle sizes, which may cause shearing at the aggregate wood fiber interface.

Laboratory Analysis

Laboratory Procedures

The laboratory test procedures were designed to complement the field performance measurements taken on the project. The main emphasis was on the moisture density relationship, particle size analysis, and on the resilient modulus of the wood fibers. Standard test procedures for subgrade soils and aggregate were used to determine the engineering properties of the material in accordance with AASHTO test procedures.

Discussion of Results

The moisture density curve is very flat over a wide range of moisture contents. The densities range from 290 kg/m^3 (18.1 lb/ft^3) at 105 percent moisture content to a maximum dry density of 293 kg/m^3 (18.3 lb/ft^3) at an optimum moisture content of 166 percent. These values are very similar to those reported by Nelson and Allen (*12*). They report a maximum dry density of 341 kg/m^3 (21.3 lb/ft^3) at a moisture content of 175 percent for cedar hog fuel. The slight difference may be attributed to differences in wood species and particle size.

A sieve analysis was conducted to determine the particle size distribution of the woodwaste material. The results are based on the average percent passing of five separate tests. The nominal maximum particle size is 25 mm (1 in.). Field observations suggest that this may be as large as 15 cm (6 in.) The analysis shows that the woodwaste is a relatively well-graded or densely graded material. It contains a broad range of particle sizes with a higher percentage of material in the No. 4 to No. 40 size classification.

The stability of typical base and subbase materials such as soil-aggregate mixes depends on several factors: particle size distribution, shape, relative density, and internal friction (*12*). Several of these factors may also be applicable to woodwaste. The elongated shape produces an interlocked structure when compacted and the gradation contains enough fine material to fill the voids without "floating" the larger particles in the mixture. These factors should contribute to the stability, shear resistance, and load distribution characteristics of the material.

Laboratory resilient modulus tests were conducted to verify back-calculated modulus values obtained in the field with an FWD. The laboratory resilient modulus results were analyzed in two ways (*11*). The first analysis treated the woodwaste modulus as a function of bulk stress as is done with coarse-grained materials (*12*). The second analysis treated the modulus as a function of deviator stress as is done with fine-grained materials (*12*). In both analyses, the woodwaste modulus did not exhibit the typical responses associated with coarse- or fine-grained materials (*12*).

The bulk stress analysis relationship,

$$Mr = K1 \times \theta^{K2} \quad (1)$$

was used to express the resilient modulus, where $K1$ and $K2$ are regression constants and θ is the bulk stress.

The modulus values for each specimen were plotted versus bulk stress on a log-log scale using Equation 1 to fit the data. Figure 5 shows the woodwaste moduli responses for Samples 1 to 3. The results do not show very good correlation with accepted methods.

The second analysis looked at the responses of modulus as a function of deviator stress. Figure 6 shows the typical relationship found in the analysis. The results show that there does not seem to be a standard relationship between modulus and deviator stress for these data. The samples have a wide variation in curve shapes. The most typical seems to be a trend toward decreasing modulus with increasing deviator stress.

Average modulus values do not represent expected values very well because of the variability found in the analysis. Laboratory modulus values range from 5 to 34 MPa (700 to 5,000 psi). The moduli do not seem to have a definite pattern with respect to stress condition, moisture content, or density at this time. More laboratory analysis should be done to better define the resilient modulus of sawmill-generated woodwaste.

FUTURE STUDIES

R-Value Study

One of the engineering properties of small-wood-particle road construction that is thought to be substantially different from conventional gravel-and-soil construction is the potential insulating effect. In cold regions, this can have a significant positive influence on the potential for frost heave, the loss of strength as a result of spring thaw, and protection of permafrost from thaw conditions. Empirical observations in Minnesota and Wisconsin indicate that there is a very significant

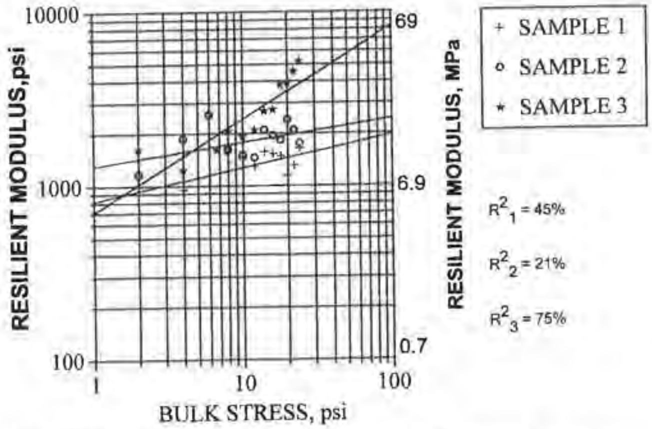

FIGURE 5 Resilient modulus versus bulk stress, Samples 1–3.

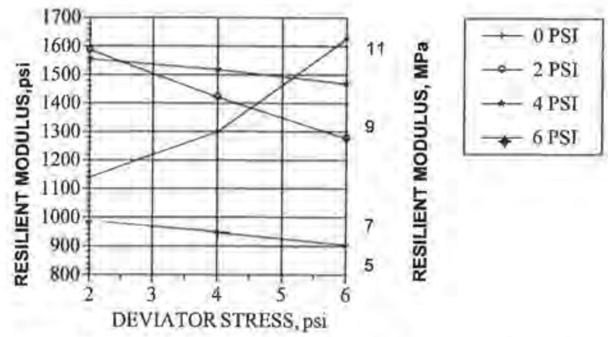

FIGURE 6 Resilient modulus versus deviator stress, Sample 1.

insulating effect from the materials, but no tests have been conducted to determine the insulating properties.

The objective of the future study is to determine the thermal resistance (*R*-value) of selected samples of chunkwood using a modified hot-box assembly. Once the laboratory tests have been conducted to determine the *R*-value for chunkwood, it is anticipated that field tests will be conducted. The tests should be in an area with enough freezing days to show the difference between traditional soil-gravel construction and chunkwood-gravel construction. With the results of the field tests, the suitability of chunkwood for construction over permafrost and frost-susceptible soils will be largely known. In severe Arctic conditions, up to 2 m (6 ft) of gravel may be needed to protect the permafrost from thawing under the road. If a foot or two of wood could reduce the amount of gravel needed, a substantial savings is possible.

Wood Preservative Study

The long-term use of small wood particles as construction material in temperate and warmer climate depends on a low-cost, low-toxicity wood preservative. Another problem that needs to be solved is the potential of the material to combust and burn. A literature review indicates that the most practical solution is borate. It is very low cost, serves as an effective fireproofing material, and has a very low toxicity. Its major defect is that it tends to leach out with repeated wetting-drying cycles. The use of geotextiles to prevent leaching should be considered. The potential to use borate as a low-cost wood preservative seems to be an idea that should also be tested.

SUMMARY

All types of wood fibers have a long history of use in road construction across the United States and British

Columbia. Wood particles have been used in highways and low-volume roads to reduce landslide potential and to cross settlement-sensitive soils such as muskeg. Many types of wood particles are being used: brush, construction slash, chunkwood, and sawmill-generated woodwaste such as bark, sawdust, and planer shavings.

The USDA Forest Service recently constructed 4 km (2.8 mi) of forest access road in Wrangell, Alaska, using sawmill woodwaste supplied by the Alaska Pulp Corporation under a cooperative agreement. This project was conducted to study the economic feasibility and the material's suitability for use in the area. As part of the study, an evaluation of the engineering performance characteristics was undertaken to develop some guidelines for future use. The study evaluated the rutting potential and road stiffness in a series of field and laboratory analyses.

Preliminary results of the engineering performance study show that sawmill-generated woodwaste is a suitable construction material for use in southeast Alaska. These materials are adequate as embankment materials or as a driving surface. When used as embankment material, a woodwaste depth of 76 cm (30 in.) seems to be the minimum depth required to carry construction traffic and subsequent heavy-duty traffic for the test sites. The woodwaste materials perform best when surfaced with 30 cm (12 in.) of crushed aggregate or 38 cm (15 in.) of shot rock. If the road is intended for light-duty recreational or administrative traffic, 15 cm (6 in.) of crushed aggregate may be adequate.

As a driving surface, woodwaste provides a soft, quiet ride. Frequently scheduled maintenance is required to repair rutting and low-frequency washboarding that is prone to develop. These can be easily corrected by blading with a standard motor grader or bulldozer. Rutting of up to 7 cm (3 in.) tends to occur within 20 to 30 round-trip truck passes. If the road has sufficient width for off-tracking, the wood fibers tend to be self-healing with respect to rutting.

Initial laboratory analysis shows that over a wide range in moisture contents, woodwaste dry density is not significantly variable. This means that layer placement and compaction with construction equipment is a viable construction technique. It is suggested that layer depths of 51 to 61 cm (20 to 24 in.) be used to maximize density. If the layers are to remain for several days before placing the next layer, occasional patching may be necessary to compensate for soft spots and material loss.

Potential future studies include an *R*-value and wood preservative study. The *R*-value study would determine the insulating properties of wood fibers for use in cold regions to cross permafrost. A wood preservative study would study the use of nontoxic chemicals and geotextiles for extending wood fiber life cycles. Both of these studies could have a large influence on the future use of wood fiber materials in road construction.

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