IJEMHS (www.ijemhs.com) Volume 31, Issue 02, Quarter 02 (2019) Publishing Month and Date: 30th June, 2019

ROADS AND AIRFIELDS CONSTRUCTION USING FIBERSTABILIZATION OF SANDS

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ABSTRACT: This paper describes laboratory and field tests conducted using a new fiber stabilization technique for sands. Laboratory unconfined compression tests using 51 mm long monofilament polypropylene fibers to stabilize a poorly graded (SP) sand showed an optimum fiber content of 1% (by dry weight). Field test sections were constructed and traffic tested using simulated C-130 aircraft traffic with a 13,608 kg tire load at 690 kPa tire pressure and a 4,536 kg military cargo truck loaded to a gross weight of 18,870 kg. Test results showed that sand-fiber stabilization over a sand subgrade supported over 1,000 passes of a C-130 tire load with less than 51 mm of rutting. The top 102 mm of the sand-fiber layer was lightly stabilized with tree resin to provide a wearing surface. Based on limited truck traffic tests, 203 mm thick sand-fiber layer, surfaced with a spray application of tree resin, would support substantial amounts of military truck traffic.

BACKGROUND

The Corps of Engineers, Engineer Research and Development Center– Waterways Experiment Station (ERDC-WES), has been working with Wright Laboratory at Tyndall Air Force Base to develop new soil stabilization techniques that reduce the time required to expand parking areas and aprons. This paper describes a new fiber stabilization technique that improves sandy soils for supporting C-130 and lighter aircraft operations. Aircraft operations in a sand environment produce deep ruts up to 356 mm, sometimes resulting in aircraft being immobilized. This new technique uses conventional mixing procedures and equipment to construct runways, taxiways, and aprons. In addition, the new stabilization technique has application for military supply roads and storage areas at remote sites.

A review of the literature indicated that different laboratory tests have been conducted on fiber-reinforced granular material, but the studies were not focused on airfield pavement or road design. Most of the studies showed improvement of soil strength properties through laboratory tests without field validation. Investigations have shown that including synthetic fibers increases the load carrying capacity (or strength) of sand and improves engineering properties such as shear modulus, liquefaction resistance, and particle interlocking (Freitag 1986; Maher and Ho 1994). The improvement of the engineering properties of the sand is influenced by the fiber content, type, length, and orientation (Gray and Al-Refeai 1986). Al-Refeai (1991) found that for fine and medium sands, no appreciable increase in the stiffness of the sand was gained by using fibers longer than 51 mm.

Field traffic tests were conducted (Grogan and Johnson 1993) to test stabilization of high plasticity clay and silty sand by inclusion of discrete fibrillated polypropylene fibers for use in pavement subgrades. Truck traffic tests on the plastic clay material, treated with fiber and 5% lime stabilization, provided up to 90% more traffic passes to failure than similar lime-stabilized test sections without fibers. Truck traffic tests on the sand material, treated with fibers in conjunction with 5% portland cement stabilization, provided 60% more traffic passes to failure than similar cement-stabilized test sections without fibers. Other traffic tests on the sand containing 0.5% fibers (25 mm long) showed some enhanced traffic performance, but the results were not considered economically practical.

OBJECTIVES AND SCOPE

The purposes of this article are to (1) describe laboratory tests conducted to determine optimum fiber content; and (2) present the results of field tests conducted showing the benefits of geosynthetic fibers for rapid airfield and road stabilization. This article was limited to laboratory and field tests that involved the use of only one type of sand and one type of fiber. Five dosage rates of fiber were evaluated during the laboratory test. In addition, a field mixing test was included to compare laboratory and field performance. During the field test, only one dosage of fiber (1%) was evaluated. The operation of a C-130 aircraft was simulated during the field test. Turning and/or braking was not included in the test. Traffic tests were also conducted using a military cargo truck (6 × 6, M923) loaded to a gross vehicle weight of 18,870 kg.

LABORATORY EXPERIMENT

Description of Materials

Sand

The sand used for the experiment was a local Vicksburg, MS, sand normally used as fine aggregate in concrete mix. The sand was a pit-run washed sand containing approximately 4% gravel sizes, no minus No. 200 U.S. standard sieve size material, and was classified as a poorly graded (SP) sand (ASTM D 2487 1992). The specific gravity is 2.65, maximum dry density is 1,886 kg/m^3, minimum dry density is 1,576 kg/m^3, coefficient of uniformity is 2, and mean diameter, D_{50}, is 0.5.

TABLE 1. Fiber Properties

Property (1)	Test method (2)	Typical values (3)
Polypropylene	ASTM D 4101 (ASTM 1995b) Group 1/Class 1/ Grade 2	99.4%
Color	—	Natural
Moisture absorption	—	Nil
Fiber length, mm (in.)	Measured	51
Specific gravity, kg/cm (lb/in.)	ASTM D 792 (ASTM 1991)	0.91
Tensile strength, kPa (psi)	ASTM D 2256 (ASTM 1995a)	275,800
Young's modulus, kPa (psi)	ASTM D 2101 (ASTM 1979)	3,102,750
Denier evaluated	Weight in grams of 9,000 m of fiber	50

Fiber

The synthetic fiber used in this investigation was a monofilament polypropylene fiber. It was selected based on a literature review conducted prior to the selection of materials. Research has indicated that the performance of the materials stabilized with the fibers increased with increased length of the fiber up to a length of 51 mm (Al-Refeai 1991). In addition, this fiber length allows for easy mixing in the field with a self-propelled rotary mixer. Table 1 shows the properties of this fiber.

Preparation

In preparing laboratory test specimens, a new method of separating the individual fibers from the yarn was developed. First, a few holes were punched with a paper hole punch near the closed end of a 125 L plastic bag. Next, a handful of yarn fibers was placed in the bag. The bag was hand-held closed around an air nozzle, inverted, and air was blown through the fibers. The air separated the fibers from the yarn effectively and promptly. The separated fibers formed fluffy bundles that resembled cotton candy. Once the fibers were separated, they were weighed and hand mixed with the sand to as uniform a consistency as possible.

The water content of the sand-fiber samples ranged between 5.3 and 7.5%. Moisture in the sand was needed to hold the sand-fiber mixture together during mixing. If the sand became too dry, the sand tended to separate from the fibers. The percentages of fiber used in the samples were 0.2, 0.5, 1.0, 1.5, and 2.0% by dry weight of sand. Material from the field mixed sample containing 2.4% of fiber was included in the laboratory tests to evaluate its performance against the laboratory prepared samples. In addition, a control sample (containing no fibers) was included in the laboratory tests.

A 305 mm length of 152 mm diameter PVC pipe was used to make the test specimens. The plastic pipe was split lengthwise and taped together to hold the specimen during compaction. After the specimen with mold was positioned in the test machine, the tape was cut and each mold half was carefully removed from the specimen. The sand-fiber mix was placed in the cylinder in five layers, and each layer was compacted using five blows of a 4.5 kg compaction hammer.

Evaluation

Specimens were evaluated by conducting unconfined compression tests. The unconfined strength tests were conducted using an Instron 4208 testing system. The Instron system consists of the test loading instrument and a computer for load-time recording of results. The test specimen was positioned in the test instrument, and a seating load of 0.45 kg was applied. This initial load was required to ensure satisfactory seating of the compression piston, and it was considered as the zero load when determining the load-deformation relation.

The load was applied to each sand-fiber specimen at a constant rate of 0.042 mm per second. Each specimen was compressed until it reached a preset axial strain of 0.08 or until it collapsed. Some of the sand-fiber samples were tested to higher deformations to evaluate the sand-fiber performance at high deformations. For example, the samples with 0.5 and 1.0% of fibers were compressed until an axial strain of 0.08 was reached. The field sand-fiber sample (2.4%) was also tested for a maximum axial strain of 0.25.

Data were collected for the five sand-fiber samples (0.2, 0.5, 1.0, 1.5, and 2.0% fibers), the field sand-fiber sample (2.4%), and the control sample (no fibers). For each specimen, the applied load and the deformation were recorded at 10 points per second. The control sample collapsed under a load of 2.3 kPa, but significant load improvements results were found for the sand-fiber samples. Very little sand had fallen from the specimens.

Fig. 1 shows plots of the load-deformation data for all test specimens for axial strain ranges from 0 to 0.05. From 0 to 0.033 of axial strain, the optimum fiber content of approximately 1% produced the maximum loads. Higher fiber contents of 1.5 – 2.4% show slow initial strength gain at low deformations with more rapid strength gains at higher deformations. Excess amounts of fiber may interfere with the grain-to-fiber contact resulting in a spongy sample that must be compressed before the beneficial grain-to-fiber interaction occurs.

Fig. 1 also shows that the field mixed sample (2.4% of fiber) performed in a similar pattern as the 2.0% laboratory prepared specimen. The results showed that the laboratory mixing adequately replicated the field mixing procedure. In both cases, the mix was uniform and the fibers were randomly distributed. It is seen that for this granular soil (SP), a significant improvement in load-carrying capacity was obtained for each sample.

Optimum Fiber Content

Figs. 2 and 3 show plots of load versus fiber content for axial strain ranges of 0.008 – 0.021 and 0.021 – 0.083, respectively. Fig. 2 also shows that for low deformations the optimum fiber content is approximately 1% (based on dry weight of sand). For larger axial strain up to 0.083, the optimum fiber content increases to 1.5%. Since low deformations are desirable under traffic wheel loads, 1% fiber was selected as optimum for use in the field experiments.

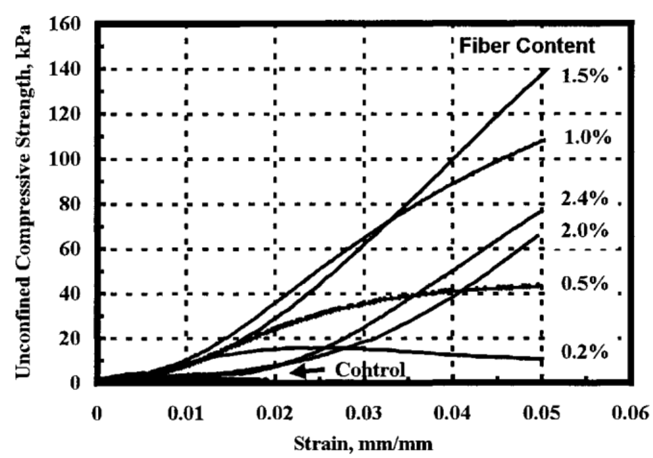

FIG. 1. Relationship between Percent of Fiber and Permanent Deformation

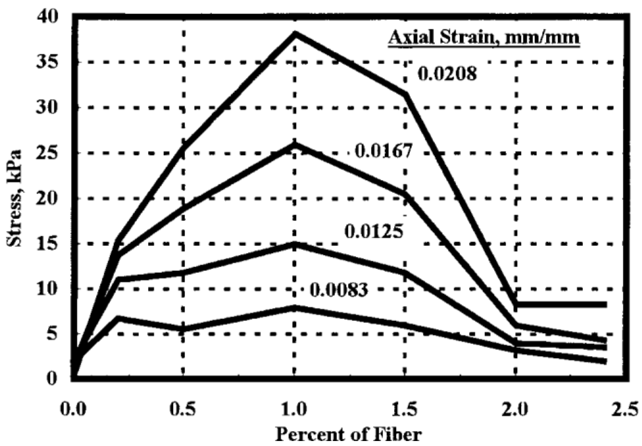

FIG. 2. Optimum Percent of Fibers (0–6 mm Deformation)

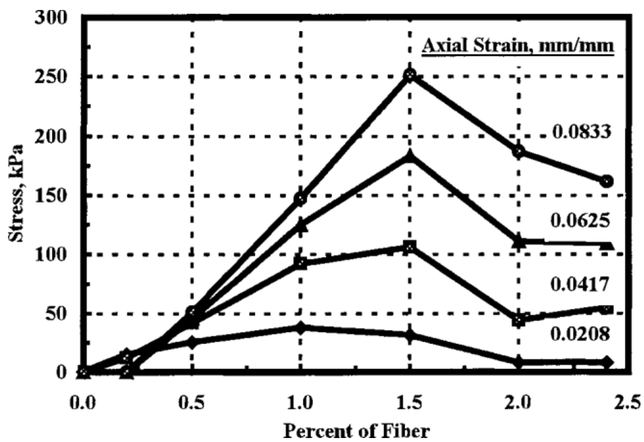

FIG. 3. Optimum Percent of Fibers (6–25 mm Deformation)

FIELD EXPERIMENTS

Description

The test section for this study was located under shelter on the WES reservation. It was constructed over the shelters's firm floor, which consisted of compacted lean clay soil. A plan and profile of the test section is shown in Figs. 4 and 5. The test section was designed to test the load-carrying capability of various fiber-reinforced sand test items under a C-130 aircraft wheel loads. All test items were constructed on a 457 mm thick sand subgrade. The test section contained two traffic lanes. Each traffic lane contained three test items. Both traffic lanes utilized a distributed type traffic (Fig. 6) over a width of five wheel paths (1,803 mm). After traffic tests were completed on lane 1, the items were reconstructed as shown in the profile in Fig. 5. Test items in traffic lane 2 were 203 mm thick, and items in traffic lanes 1 and 1A were 305 mm thick. Sand grid was included in some test items to provide additional stability to the base layer. A resin modified emulsion bonding agent was included in some items to provide additional base stability and a wearing surface for the C-130 wheel loads.

Materials

Sand and Fiber

The sand used for the subgrade and base layer was the same sand described earlier in the initial sand fiber experiments and laboratory tests sections of this article. The monofilament fiber used in the tests was the same 51 mm long polypropylene fibers described earlier in the initial sand-fiber experiments and laboratory tests sections of this article.

Tree Resin

Tree resin is a resin modified emulsion that is non– water soluble and has a high bonding strength. It was developed specifically for use in pavement applications, dust control treatment, and erosion control. It contains selected fractions of natural tree resins combined with a strong bonding agent. It

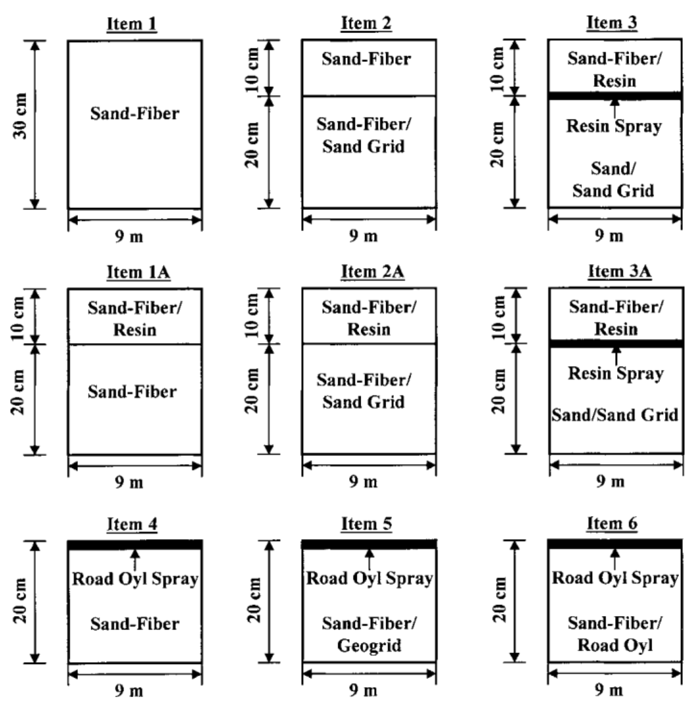

FIG. 4. Plan and Profile of Test Section, Lanes 1 and 2

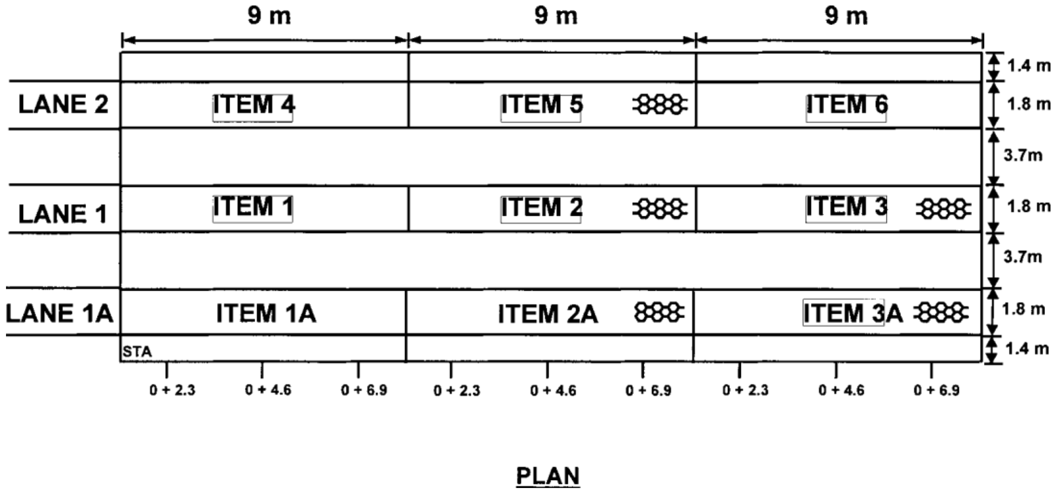

FIG. 5. Plan and Profile of Test Section, Lane 1A

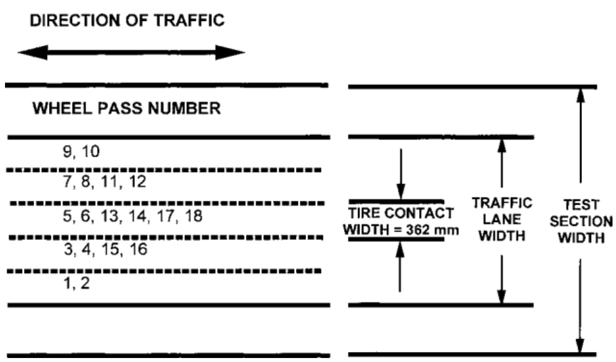

FIG. 6. Traffic Pattern for Single-Wheel Test Cart

can be field mixed with premoistened materials or diluted with water and sprayed on for surface penetration. It is petroleum free and can be cold-applied. It is environmentally friendly and available for bulk shipments, 208 L drums, and 1,041 L pelletized bulk container package (SSPCo 2000). The cost is about $1.12/L.

Sand Grid

Sand grid [national stock number (NSN) 5680-01-198-7955] is a plastic geocell material designed for confinement of sand or other cohesionless materials to produce a load-distributing base layer. Uses of the grid include road and airfield pavements, airfield crater repair, erosion control, field fortifications, and expedient dike repair. The plastic grids are manufactured and shipped in collapsed 102 mm thick, 50 kg sections. Each expanded grid section is 2.4 × 6.1 m and contains a honeycomb arrangement of cells. Each cell has a surface area of 25,161 mm^2 and a depth of 203 mm. Use of sand grid is covered in Army FM 5-430-00-1/AF JPAM 32-8013, Vol. I (Headquarters, Departments of the Army and Air Force 1994).

Construction

The test section was constructed during the period July–August 1995. All work was accomplished by WES personnel using conventional construction equipment. The test section items were constructed over an 457 mm thick sand subgrade that was leveled and compacted using a D4 tractor. The sand subgrade was installed on the firm (CBR > 10) CL soil floor in the Hangar No. 4 shelter at WES.

Sand Grid Installation

Sand grid for test items 2, 3, and 5 was installed using a lightweight tubular stretcher frame. The 6.1 m long frame was placed on the subgrade and the sand grid was expanded and attached to vertical prongs at each end of the frame. The frame also contained two rubber straps with hooks along each side rail to secure the grid to the frame. The stretcher frame with attached sand grid was then flipped over. Although the stretcher frame is not required for sand grid installation, it is useful when only a limited number of workers are available and it ensures correct 6.1 m expansion of the grid for proper installation. Sections of grid were joined using hog rings. Two lanes of grid were installed in each item to ensure the joint between grid sections would line up in the middle of the traffic lanes. Sand without fibers was then installed in item 3 and compacted using six passes with a smooth drum vibratory compactor.

Sand-Fiber Mixing and Installation

The sand-fiber mixture used in items 1, 2, 4, and 5 was mixed at a working area adjacent to the test section site. After mixing, the sand-fiber material was installed and compacted in the test section. The moisture content of the sand was approximately 4%. A total of 1% fibers (by dry weight) was mixed into the sand. The fibers were mixed into the sand using four passes with the self-propelled rotary mixer used by U.S. Army Engineers (Fig. 7). The sand-fiber layer was then turned

FIG. 7. Mixing Fiber into Sand Using Rotary Mixer

FIG. 8. Installing Sand-Fiber Mixture into Sand-Grid

TABLE 2. Sand-Fiber/Tree Resin Application Summary

Test item number (1)	Field mixed tree resin application rate (liter m[2] per mm of depth) (2)	Surface Spray Application: Tree resin quantity (L/m^2) (3)	Surface Spray Application: Water dilution ratio water/ tree resin (4)
3 and 3A	1	4.1	No dilution
4	—	4.1	No dilution
5	—	4.1	No dilution
6	0.25	4.0	No dilution
1A	0.6	2.05	2/1
2A	0.3	3.08	2/1

over using a front-end loader and the remaining fibers were placed and mixed using four passes of the rotary mixer to ensure a uniform sand-fiber mixture for the whole layer. Most of the clumps of fibers had disappeared and the hair-like fibers were uniformly mixed throughout the sand.

Fig. 8 shows installation of the sand-fiber mixture into the sand grid cells, as was done in items 2 and 5. The sand-fiber mixture tended to hang up on the top of the cell walls. In some cases the sand-fiber mixture would bridge over the cells, leaving a void in the grid cell. The entire surface of the item was trafficked using the end-loader tires to ensure no voids existed in the grid cells. The sand-fiber-filled grids (203 mm depth) were then compacted using six passes with the smooth drum vibratory compactor. After compaction, the surface was smooth and flat.

Metal grade stakes were used to ensure an even 203 mm deep base layer of sand-fiber. The sand-fiber surface was difficult to smooth using the end-loader bucket. A road grader would have left the surface equally as rough. The sand-fiber mixture tends to act in clumps and resist smoothing efforts with a blade on construction equipment. The sand-fiber mixture was sprayed with water. The 203 mm thick sand-fiber layer was installed in items 1 and 4. The 102 mm thick sand-fiber surfacing was then installed over items 1 and 2, sprayed with water, and compacted using six passes with the vibratory roller.

Sand-Fiber/Tree Resin Mixing and Installation

The sand-fiber/tree resin material was constructed by field mixing the materials at the adjacent work area and then installing and compacting the mixed material in the test section. Table 2 summarizes the sand-fiber/tree resin applications. The quantities of tree resin listed are for concentrated (undiluted) products as received from the manufacturer. The residual binder content is approximately 48–50%.

First, the sand and fiber (1% by weight) were mixed as described earlier. The required amount of tree resin was then poured onto the sand-fiber layer and mixed into the sand-fiber layer using two passes of the rotary mixer. The mixture was then turned over using the front-end loader and remixed with two additional passes with the rotary mixer. The mixture was then piled prior to installation in the test section. The fiber and tree resin were very uniformly mixed with the sand.

The sand-fiber/tree resin base material for item 6 was installed in one layer and compacted with six passes with the smooth drum vibratory compactor to form an 203 mm thick base layer. The 102 mm thick sand-fiber/tree resin surfacing material for item 3 was installed in one layer after the surface spray application of tree resin had been applied. This surfacing layer was compacted with six passes of the smooth drum vibratory compactor. The surfacing for items 1A and 2A were constructed from the remains of items 1 and 2. The 102 mm thick surfacing from items 1 and 2 were removed, the tree resin was mixed in, and then it was reinstalled and compacted with six passes of the smooth drum vibratory compactor.

Tree Resin Surface Spray Applications

The surface of each test item receiving a tree resin spray application was first sprayed with approximately 4.1 L of water per square meter. The water removed any dust from the surface and aided tree resin penetration into the sand-fiber surface. The tree resin was then applied using a 114 L paint pot and air pressure. The tree resin was pumped through a garden hose containing an ordinary spray nozzle using 103 kPa air pressure. The 36.6 m^2 surface area of each item was divided into thirds using string lines, and the measured quantities of tree resin were uniformly sprayed on each section. When applied full strength (no dilution with water), the tree resin (at an application rate of 4.1 L/m^2) penetrated approximately 25.4 mm into the sand-fiber surface. The tree resin was diluted with water for application on items 1A and 2A in order to aid penetration into the already partially stabilized sand-fiber/tree resin surfacing. Test items 1 and 2 contained no tree resin.

Completed Test Section

The completed test section is shown in Fig. 9. Item 1 is on the right and item 4 is on the left in the foreground of Fig. 10. The painted lines on items 1 – 3 (on the right) are guides for applying the traffic pattern. All traffic wheel loads were applied between the two white lines in the center portion of each test item according to the pattern in Fig. 6. A well-graded crushed stone base material was used as shoulders (0.61 m wide) on the outside test section edges and in the area between

FIG. 9. Complete Test Section

FIG. 10. Test Cart with 13,608-kg Single-Wheel Assembly

the two test lanes (1.5 m wide). The crushed stone base served to support load cart tires that would have to run in these locations. The crushed stone material between the test lanes was sloped to match a 102 mm height differential between lanes 1 and 2. Since the entire test section was constructed above ground level, sand shoulders were extended 1.2 m past the crushed stone shoulders to help prevent lateral movement of the test items during traffic tests.

Behavior of Field Test Section under Traffic

Simulated C-130 Aircraft Traffic

Test traffic was applied using the single-wheel-assembly test cart shown in Fig. 10. The cart was equipped with an outrigger wheel to prevent overturning and was powered by the front half of a four-wheel-drive truck. The test wheel and tire were the type used for a C-130 aircraft. The tire was inflated to 690 kPa. The tire load was 13,608 kg with a contact area of 199,354 mm^2. The measured tire contact width was 362 mm, and length was 648 mm. Test traffic was applied by driving the test cart (approximately 6.4 – 8.1 km/h) forward and then in reverse over the entire length of the test section in the same wheel path. The load tire was then moved over one wheel width and traffic continued. This procedure was followed using the lateral traffic distribution pattern shown in Fig. 6 until the loading pattern was completed. The loading cycle was then repeated until 1,000 traffic passes were applied.

Failure Criteria

Failure criteria for unsurfaced or gravel surfaced pavements is 76 mm of rutting. In emergency situations C-130 aircraft can operate in much deeper ruts than 76 mm. For this study, maintenance on test items was performed when rut depths reached approximately 76–102 mm.

Maintenance

The surface of test items 1 and 2 contained no tree resin stabilizer. As the moist sand-fiber surface of these items dried during traffic, the load cart tires and test load tire would pull the fibers out of the sand surface. This problem did not occur when the surface was kept moist by spraying with a garden hose twice a day. Small amounts of sand-fiber (used in item 2) or sand-fiber/tree resin (used in items 3, 5, and 6) patching material were used to repair spot locations where 76 – 102 mm ruts developed. A pitchfork worked much better than a shovel when handling the patch material. The fibers prevent a shovel from penetrating into a pile of patch material. The patched area bonded with the item surface and stayed in place during additional traffic passes. Patching sand-fiber layers with like material was easy and effective.

Rut Depth Measurements

Rut depth measurements were recorded at intervals throughout the traffic test period. Rut depth measurements were made by placing a metal straight edge across the traffic lane at three locations in each item (item quarter points) and measuring the maximum rut depth using a ruler. The rut depth included both the permanent deformation and the upheaval within the traffic lane. The average of the three readings was recorded as the average rut depth for a given traffic pass level.

Rut depth measurements for these items are shown in Fig. 11. Rutting for items 1 and 2 (wet sand-fiber surfacing) was about the same. Both items had rut depths of 76 – 102 mm after only 200 passes and no significant increase in rut depth from 200 to 1,000 passes. When the 102 mm surfacing of these items was reconstructed to form items 1A and 2A (sand-fiber/ tree resin surfacing), rut depths were under 51 mm after 1,000 passes. Since the only difference in items 1 and 2 (also 1A and 2A) was the sand grid in items 2 and 2A, rut depth plots in Fig. 11 shows no increase in performance due to the sand grid.

Rut depth measurements for item 4 (203 mm sand-fiber with tree resin spray-on surfacing) averaged 127 mm of rutting after only 25 passes. On the 25th pass, the load tire sheared the sand-fiber layer, causing the load cart vehicle to become immobilized. Although rutting in items 5 and 6 was slower to develop, significant patching along the entire length of each item was required to keep the load wheel from shearing through the center wheel path of the tracking lane.

Cross Sections

Surface cross sections were recorded at intervals throughout the test traffic period. The cross sections of the traffic lanes were recorded at the same item quarter point locations where the rut depth measurements were made. One measure of traffic performance obtained from the cross-section data was the average maximum permanent surface depression (ignoring any upheaval). Typical cross-section plots at various traffic pass levels were also useful in describing the performance of test items.

Permanent Surface Depression

Fig. 12 shows a record of the maximum permanent surface depression for items 1, 2, 3, 1A, 2A, and 3A. Each plot rep-

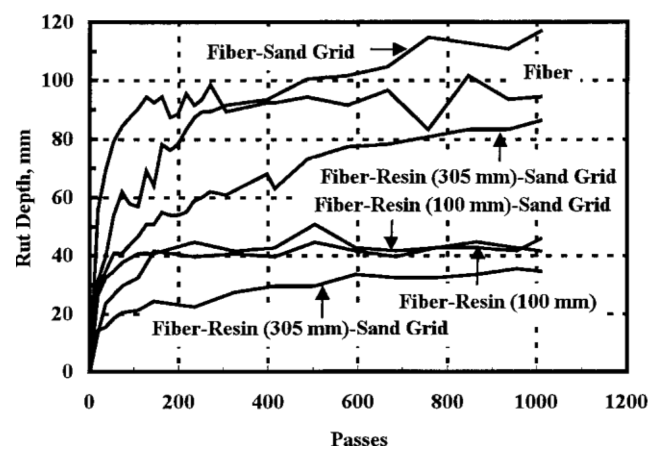

FIG. 11. Rutting versus Passes, 305-mm-Thick Items, Lanes 1 and 1A

resents the average maximum surface depression based on the three cross-section locations for each test item. In general, the permanent surface depression plots follow the same pattern as the rut depth plots. The effects of a small amount of patching material (approximately 1 to 2 ft^3 per item) on permanent depression can be seen for items 2 and 3 in Fig. 12. Only small amounts of patching material (the same material used in item surfacing) was needed to stabilize or retard further increases in permanent depression with additional traffic passes. However, in item 5 a large quantity of patching material (approximately 0.28 m^3) was required to reduce the permanent depression.

Typical Cross Sections of Permanent Deformations

Fig. 13 shows typical cross sections of permanent deformations of the various test items at various pass levels. This figure shows that a lot of deformation occurred within the traffic lane and very little upheaval (negative deformation) occurred within or outside the traffic lane. This permanent deformation pattern indicates that most of the deformation was a result of increased densification of the sand-fiber base layer or subgrade sand due to the traffic loads. Some of the performance improvement of items 1A– 3A over items 1 – 3 was probably due to the increase in base and subgrade compaction caused by traffic loads on items 1 – 3. The load cart sheared through item 4 on the 25th pass and became immobilized. Upheaval outside the traffic lane on the west side of item 5 after 180 passes was caused by rutting in the subgrade under the 203 mm thick sand grid layer. The deformation pattern for item 6 was similar to item 4, but its upheaval was similar to item 5. In summary, the permanent deformation data showed that all the 203 mm thick items were too thin to support the tire loads applied.

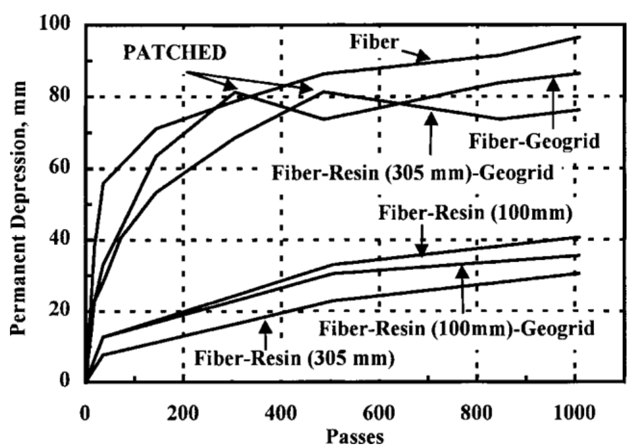

FIG. 12. Permanent Surface Depression, 305-mm-Thick Items

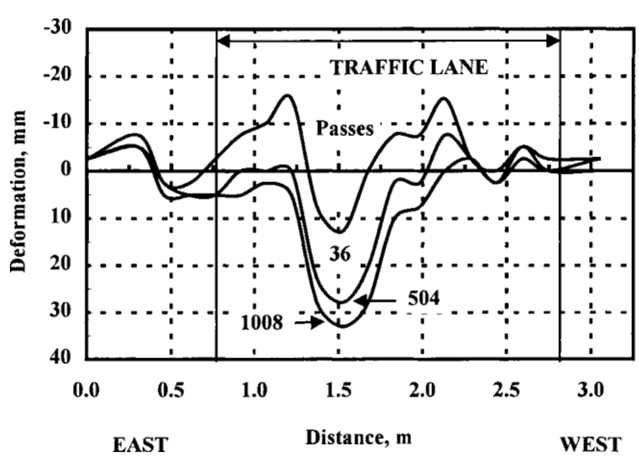

FIG. 13. Typical Cross Sections of Permanent Deformation, Item 1A

Application of Military Truck Traffic

After the C-130 load cart tests were completed, truck traffic was applied to test items 1A– 3A and items 5 and 6. A 5 ton military cargo truck loaded to a gross weight of 18,870 kg was used. A total of 120 truck passes were applied to items 5 and 6 and 1,000 passes were applied to items 1A– 3A. A uniform traffic distribution was applied over the entire 3.66 m wide test surface in items 1A– 3A. The truck traffic was beneficial in that it smoothed out the rutting caused by the load cart tests. Items 1A– 3A could have supported substantial amounts of additional truck traffic. These limited test results indicated that the 203 mm thick items could easily support large amounts of truck traffic. Test results also indicated that a simple spray-on application of tree resin makes an excellent wearing surface for sand-fiber base layers for truck traffic.

ANALYSIS AND CONCLUSIONS

The following analysis and conclusions are based on tests with one type of sand and one fiber length and type. The tests did not include braking or turning traffic conditions. The fiber content and tree resin requirements may change for different sand types.

Thickness Requirements

C-130 Aircraft

Fig. 14 shows the results of rutting versus passes for load cart traffic on the 203 mm and 305 mm thick sand-fiber items tested. The 203 mm thick sand fiber (item 4) was too thin to support any significant amount of C-130 type traffic. The 305 mm thick sand-fiber (item 1) supported the traffic for 1,000 passes with rut depths averaging 89 – 102 mm. When the top 102 mm of the sand-fiber layer was lightly stabilized with tree resin (item 1A), rut depths were kept less than 51 mm after 1,000 passes. All significant rutting occurred within 200 traffic passes. Rut depths at 1,000 passes were about the same as they were at 200 passes. Based on the tests conducted, for sand-fiber stabilization over a sand subgrade (medium to coarse sand), the stabilized thickness requirements should be

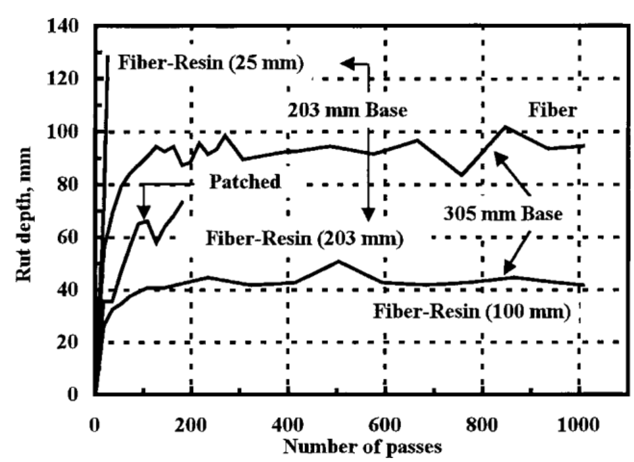

FIG. 14. Rutting versus Passes for Load Cart Traffic, 203- and 305-mm-Thick Sand-Fiber Items

305 mm. This thickness should support over 1,000 C-130 aircraft passes.

Truck Traffic

Based on the limited truck traffic tests, an 203 mm thick sand-fiber layer is sufficient to support substantial amounts of military truck traffic.

Surfacing

C-130 Aircraft

Based on the performance of items 1A, 2A, and 3A, stabilizing the top 102 mm of the sand-fiber layer with tree resin was sufficient in providing a wearing surface that kept rut depths to less than 41 mm after 1,000 passes. The amounts of tree resin tested ranged from 1.36 to 4.53 L/m^2 per millimeter of depth (based on undiluted quantities). The higher quantity of tree resin produced a solid asphalt-concrete type surfacing that should provide for better breaking and turning performance. For best results, the tree resin should be admixed into the sand-fiber material using a self-propelled rotary mixer. For adequate traffic performance, it is recommended that 9.05–18.10 L/m^2 of undiluted tree resin be admixed into the top 102 mm of the sand-fiber base layer and compacted using a smooth drum vibratory compactor.

Truck Traffic

A spray-on surfacing of tree resin (3.79 L/m^2 undiluted) penetrates approximately 25 mm into the sand-fiber surface and provides an excellent wearing surface for truck traffic. The top 25 mm of the sand-fiber surface should be moist to aid the penetration of the sprayed-on tree resin.

Compaction Requirements

C-130 Aircraft

The only compaction applied to the 457 mm thick sand subgrade was from the tracks of a D-4 tractor and a front-end loader during construction. The sand was too unstable to support the smooth drum vibratory compactor. Compaction using six passes of the smooth drum vibratory compactor on the 203 mm thick sand-fiber layer and six additional passes on the 102 mm thick surfacing may not have been sufficient to prevent compression of the subgrade sand during traffic tests. Items 1 – 3 had permanent depressions of about 76 mm after 200 – 400 load cart passes. However, when the surfacing of item 3 was patched lightly and leveled to form item 3A, only slightly more than 25 mm of additional permanent depression resulted after 1,000 additional load cart passes. This indicates that the compaction applied to the surface of items 1 through 3 probably should have been greater. For expedient pavement applications, the six passes of vibratory drum compaction should be adequate. Minor maintenance of filling and releveling ruts after 400 aircraft passes would produce a smoother surface that would prevent any significant future rutting.

Truck Traffic

A total of six passes with the vibratory drum compactor was adequate for truck traffic.

Use of Sand Grid

Sand grid filled with sand (203 mm thick layer used in items 3 and 3A) can be substituted for sand-fiber for C-130 pavement applications if surfaced with 102 mm of sand-fiber/tree resin surfacing. Sand grid filled with sand-fiber, items 2 and 2A, did not offer any performance improvement over sand-fiber, items 1 and 1A.

Cost

Sand-Fiber

Test quantities of fibers used in this study cost \$3/kg. The cost of bulk quantities is not known, but should be substantially less. The cost of fibers to stabilize (using 1% fibers by dry weight of sand) a 305 mm thick layer of sand was \$17/m^2 of test surface. Fiber for a 203 mm thick road would cost \$11/m^2 of road surface.

Tree Resin

Tree resin costs \$1.12/L in 208 L drums and would cost approximately \$0.53/L in bulk. Cost of stabilizing the top 102 mm of sand-fiber surface would be \$10.12 – \$20.24/m^2 of pavement surface (for 7.6 – 15.1 L) of drum tree resin). If bulk quantities of tree resin are used, the cost would drop to \$4.74–\$9.47/m^2 of pavement surface. A road surface with 3.8 L of tree resin/yd^2 would cost either \$2.37 or \$5.06/m^2 of pavement surface depending on whether bulk or drum material was used.

Total Material Cost

Assuming the sand is in place, the total material cost for a stabilized 305 mm thick sand-fiber pavement with tree resin surfacing would be \$21 – \$37/m^2 of pavement, depending on the quantity and type container used for the tree resin. For comparative purposes, the cost of AM2 Airfield Landing Mat is approximately \$172.22/m^2. Cost for a 203 mm (8 in.) thick sand-fiber road surfaced with tree resin would range between \$13.46 and \$16.15/m^2.

RECOMMENDATIONS

Field Demonstration

Based on the results of this investigation, the monofilament fibers showed great potential for use in rapid stabilization of sandy soils. Field demonstration tests are needed to test sand-fiber stabilization performance under actual C-130 landing, takeoff, braking, and turning operations to obtain a better perspective of the benefit of this fiber. Field demonstration tests are also needed to test the durability and maintenance requirements for sand-fiber stabilized military roads.

Additional Research Needs

Results of this study show great potential for military airfield and road applications using sand-fiber stabilization techniques. Additional research must be conducted before design guidance for global applications is developed. Future research on sand-fiber stabilization should address the following: (1) effect of sand type (only one sand type was studied in this work); (2) effect of fiber length on construction and performance; (3) other types of fibers (such as fibrillated fibers and recycled materials); (4) surfacing stabilizers other than tree resin; and (5) traffic performance at reduced fiber contents.

ACKNOWLEDGMENTS

The research reported herein was sponsored by Headquarters, U.S. Air Force Civil Engineering Support Agency and Tyndall Air Force Base. The support of the U.S. Army Engineering Research and Development Center, Waterways Experiment Station, is gratefully acknowledged.

The views expressed in this paper are the views of the writers, who are responsible for the facts and accuracy of the data. The contents do not necessarily reflect the official views or policies of the Waterways

Experiment Station, Departments of the Army. This paper does not constitute a standard, specification, or regulation.

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