Carpet Waste for Soil Stabilization

Youjiang Wang
School of Textile & Fiber Engineering
Georgia Institute of Technology

A Joint Effort by
Georgia Tech, Industry, GDOT, ACCG & Counties, Others
Supported by
CCACTI, American Plastics Council, Industry

2nd Conference on Recycling of Fibrous Textile & Carpet Waste
May 19-21, 1997, Atlanta, GA
Goal

To utilize carpet/textile/carpet waste
- post consumer: 8 billion lb/year (2% of MSW)
- including carpet waste: 4 billion lb/year

for useful applications
- **better roads**: performance & durability
- **lower cost**: reduced construction/maintenance cost
- large quantity: potentially billions of lbs/year
- most types of waste suitable, those with 25% dirt

based on proven technology
Carpet waste

- **Industry waste**
  - Excellent effort by industry in waste reduction
  - Reduced to about 40 million lbs/yr (Dalton area)
  - "Complete" re-use not far away

- **Post consumer**
  - About 4 billion lbs/yr to landfills (4000 million lbs/yr)
  - 1% total MSW. % Higher based on volume
  - Hard to handle by landfill equipment.
  - Very "durable": low rate of decomposition
  - Contains 25% dirt
  - Difficult to recycle
Components in a carpet

**Typical Carpet (oz/sq yd)**
- Face Yarn: 38
- Backing: 5
- SBR: 7
- CaCO3: 21

**Used Carpet (%)**
- Face Yarn: 40.0%
- Backing: 5.0%
- SBR/CaCO3 adhesive: 30.0%
- Dirt: 25.0%
Two promising applications

- Carpet waste fiber reinforced concrete for infrastructure construction
  - Laboratory & full scale studies conducted
- Carpet waste fiber reinforced soil for road construction
  - Comprehensive study underway
Fiber reinforcement of soil

- It works, naturally:
  - Slope stabilization by plant roots
  - Animal habitats from soil with fibers & sticks
- Long history of uses:
  - Straw reinforced clay for building bricks
- Engineering studies:
  - Since 60s with natural & synthetic fibers. Property enhancement widely reported
- Applications in the U.S.:
  - Synthetic Industries, Inc.: Fibergrids®, Patents on fiber/soil tech
  - Studied & used by several states & military
Previous studies

- Fibergrids(R): fibrillated virgin polypropylene
- Test tracks with various sections
- 18,000 lb axle load
- Failure defined as 3" rut depth
- Soils: silty sand (SS), SS+5% lime, SS+5% cement
- 0.3, & 0.5 wt% fiber added
Test track (6" & 12" thick)

The layout of the test road provided for the evaluation and comparison of FIBERGRIDS® reinforcement with several soil configurations.
12" silty sand, PP fiber
6" clay+5% lime, PP fiber
## Benefits of fiber reinforcement

<table>
<thead>
<tr>
<th>MATERIAL TYPE</th>
<th>FIBER % D.W</th>
<th>FIBER BENEFITS</th>
<th>LAB PERFORMANCE TESTING</th>
<th>RESULTS ANTICIPATED</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAND</td>
<td>0.2</td>
<td>+ Shear Strength + Bearing Capacity + Trafficability + Toughness</td>
<td>- Triaxial Shear (uu,cu) - California Bearing Ratio</td>
<td>+ Shear Strength + CBR + Friction Angle</td>
<td>- Pavement Thickness' + Steepened Slopes + Costs: Slope Maintenance</td>
</tr>
<tr>
<td>SAND (+) 3-5%</td>
<td>0.2</td>
<td>+ Flexural Strength +/- Compressive Strength + Residual Strength + Trafficability + Toughness + Resistance to Cracking</td>
<td>- Flexural Beam - Unconfined Compression</td>
<td>+ High % Retained Strength + Load Carrying in Post Peak</td>
<td>+ Trafficability (USCOE) - Reflective Cracking - %Portland Cement Required</td>
</tr>
<tr>
<td>PORTLAND CEMENT</td>
<td>0.2</td>
<td>+ Shear Strength + Compressive Strength + Residual Strength + Toughness + Resistance to Thermal &amp; Moisture Degradation</td>
<td>- Triaxial Shear (uu,cu) - Unconfined Compression</td>
<td>+ Shear Strength + Comprsv. Strength + Load Carrying in Post Peak + High % Retained Strength</td>
<td>- Reflective Cracking - Costs: Slope Maintenance ~Testing: Moisture Sensitive</td>
</tr>
<tr>
<td>SILT</td>
<td>0.2</td>
<td>+ Shear Strength + Compressive Strength + Residual Strength + Toughness + Resistance to Thermal Compression &amp; Moisture Degradation</td>
<td>- Triaxial Shear (uu,cu) - Unconfined Compression</td>
<td>+ Shear Strength + Comprsv. Strength + Load Carrying in Post Peak + High % Retained Strength</td>
<td>- Reflective Cracking - Costs: Slope Maintenance</td>
</tr>
<tr>
<td>CLAY</td>
<td>0.2</td>
<td>+ Shear Strength + Toughness + Resistance to Thermal &amp; Moisture Degradation</td>
<td>Direct Shear</td>
<td>+ Cohesion (C)</td>
<td>- Costs: Slope Maintenance - Desiccation Cracking ~Testing: Moisture Sensitive</td>
</tr>
<tr>
<td>CLAY (+) 3-5% LIME</td>
<td>0.2</td>
<td>+ Flexural Strength +/- Compressive Strength + Residual Strength + Trafficability + Toughness</td>
<td>Flexural Beam Unconfined Compression</td>
<td>+ Flexural Strength + Comprsv. Strength + High % Retained Strength + Loads Carried @ High Defltn</td>
<td>+ Trafficability (USCOE) - Reflective Cracking - % Lime Required</td>
</tr>
</tbody>
</table>
Waste fiber for soil reinforcement

- Waste fibers expected to enhance soil properties in a similar manner as virgin fibers
- Significant advantages for road construction
  - Better performance, longer lasting roads
  - Lower cost possible for construction
  - Need less soil, right-of-way, time
  - Less environmental impact resulted
Slope failure & design

- Steeper slope possible with increase shear strength
Examples: steeper slopes

- A 20’ high, 1 mile long slope: if slope angle increased from 20° to 30°, slope
  - Save 40,000 cubic yards of soil
  - Width reduced by 20’
Example: pavement subgrades

- Pavement: 1 mile long, 50’ wide
  - Fiber/soil subgrade: 6” thick, 1 wt% fiber
  - Use 262,000 lb carpet waste

- 4 million miles roads in US. If 0.5% (20,000 miles) of roads are rebuilt with carpet waste in subgrades
  - Need over 4 billion lb!

- Other uses such as slopes, embankments etc. also significant
On-going project

- A true partnership effort
  - Carpet/fiber industry
  - Synthetic Industries, Inc.: technology & experience
  - Academic: GIT School of Textile & Fiber Eng, School of Civil & Env. Eng.
  - End users: Georgia DOT, GA counties, ACCG
  - Government agencies: PPAD, State Purchasing, CCACTI, ...
  - Organizations: American Plastics Council, ...
Objectives

- Fiber configuration characterization, processing parameters
- Engineering properties of fiber/soil mixes
- Field testing
  - Building test road sections
    - on different types of soils
    - county secondary (unpaved) roads
  - Slope repair, road sections by GDOT
- Optimization, economic analysis
Fiber characterization

- Fiber processing
  - Effect of number of passes

- Characterization
  - Objective assessment of processed fibers: needed for engineering applications
  - Applicability of methods being evaluated
    - wool, bast, HVI for cotton, image analysis, …
  - statistical analysis
Fiber L & W by image analysis

- Can determine length & width of fibers
- Can differentiate face yarns and backing fibers
- Length distribution consistent with manual measurements
- Fibers must not touch each other
- Need formal procedure to prepare sample
Laboratory testing

- **Tests at GIT**
  - Silty sandy soil
  - Carpet trim fiber; 3/4"; 0, 1 & 2 wt%
- **California Bearing Ratio (CBR) test:**
  - "punching shear" loading condition
  - tested "as compacted", "soaked"
  - Strength not strongly affected by fibers for this type of soil
- **Proctor test:**
  - Dry density & optimum moisture content depend on fiber %.
Effect of fiber on compaction

Fig. 1 - Change in Maximum Dry Density of 15 CBR Samples - From As Compacted to Saturation

Fig. 2 - Moisture-Density Relationship for Fiber Reinforced Soil at Different Fiber Contents
Test curves failure modes

Unsaturated Triaxial Tests, Confined at 5 psi (34.5 kPa)

Principle Stress Difference, $\sigma_1 - \sigma_3$ (kPa)

Axial Strain, $\varepsilon$ (%)
Soil types in Georgia

Ridge & Valleys
Clayed silts with some sands
Class I, II, & III

Piedmont & Mountain
Silty sands, sandy silts, silty clays
Class III, some Class II

Upper Coastal Plain
Sands, sandy clays, & clays
Class I, II, & III

Mid Coastal Plain
Sandy Clays, silts, organic soils
Class I, II, III & IV

Lower Coastal Plain
Sands (fine & coarse)
some clayed sands, organic silts & clays
Class I, II, III & IV
Field trials

- Candler County: 10/28/96
- Habersham County: 11/5/96
- Wilkinson County: 12/4/96
- Candler County: 10/28/96
- Brooks County: 12/10/96
Typical field trial

- 4 sections: 100 ft each
  - Controls: No fiber, two virgin PP Fibers
  - Carpet waste: 15 lb/yd², 3 wt % (fiber+SBR etc)
- Procedure
  - Rip soil to a 6” depth, add gravel if needed
  - Spread fiber
  - Blend fiber into soil
  - Smooth and compact
Installation: rip soil, mix gravel
Installation: spread fiber
Installation: blend fiber
Installation: compaction

1. Compaction equipment in use.
2. Rolling the soil.
3. Rolling the soil with a roller.
Observations

- Fibers with lengths up to 2-3” can be mixed into soil. Over processing undesirable.
- Fibers are very effective in certain types of soils; sections with fibers lasted much longer. Appears less effective in unpaved roads with sandy soils.
- Further testing underway.
Waste fibers can enhance loading capacity & stability of soil structures. May bring better, more reliable, longer lasting roads at lower cost.

Effort underway involving industry, academia, users (GDOT, counties), and government agencies. Results to date encouraging

Potential to reduce needs for landfills of carpet waste. May apply to other textile waste.