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# Field Performance Testing of Improved Engineered Wood Fiber Surfaces for Accessible Playground Areas

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# Abstract

Some engineered wood fiber (EWF) surfaces on playgrounds are soft and uneven, which creates difficulties for those who use mobility aids, such as wheelchairs and walkers. The outdoor field testing reported in this study is part of an effort to stabilize EWF to improve accessibility. The concept is to mix a binder with the upper surface of EWF to create a stiff (firm) and scuff-resistant (stable) composite overlayer. Latex, silicone, and polyurethane binders were evaluated on small plots during a 6-month outdoor trial in Wisconsin. Tests were performed at regular intervals to provide a quantitative measure of accessibility. After 6 months of exposure, all the surfaces passed the existing specifications for impact attenuation of playground surfaces. Exposure changed impact performance of all systems except the unsurfaced (without an additive) EWF. The latex and polyurethane stabilizers consistently met accessibility requirements. One polyurethane formulation produced a hard brittle shell that became even harder with exposure and age, which might increase the injury rate for falls on that surface. The silicone system failed to maintain integrity adequately during the rain/dry cycles of the test. Moisture measurements indicate that the bonded surfaces retard drying of the underlying EWF, which may have long-term implications for the rate of decay for these systems.

Keywords: engineered wood fiber (EWF), accessibility, playground surface, field performance testing

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# Field Performance Testing of Improved Engineered Wood Fiber Surfaces for Accessible Playground Areas

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## Background

Traditional engineered wood fiber (EWF) meets nearly all safety-related expectations of a play surface. The primary function of EWF playground systems is to prevent head and limb injuries to playground users by absorbing impact energy. One barrier to using EWF for playgrounds is the softness and unevenness of the material, which creates difficulty for those who use mobility aids, such as wheelchairs and walkers. In our initial work (Laufenberg and others 2003), processing techniques and binders were developed and evaluated to produce wood-resin composite playground surfaces. Our goals were to enhance user safety by providing adequate absorption of impact-related energy and to improve accessibility for users of wheelchairs and walkers. The EWF-resin composite systems developed consisted of a combination of a resin and EWF in a thin top surface layer over unmodified EWF.

We identified designs using compatible resin (i.e., latex, silicone, and polyurethane) binders and various species and textures of EWF. Adhesive binders were chosen for their inert or nontoxic nature and for the retention of a natural look. Consideration was given to the need to add materials and for the possibility of patching the surfaces to make them level after a major impact event. A service life of 3 to 5 years for the playground surface was considered adequate time for the binder to act prior to renewing the surface by adding EWF. Because stabilized EWF systems had not been used for playground surfaces, there was no guarantee or warranty that they would function for that extended period.

The preliminary evaluation included laboratory testing of energy absorption and surface firmness on trial surfaces in 0.5- by 0.5-m (18- by 18-in.) plywood boxes at a uniform depth of 0.3 m (12 in.). In phase I studies (Laufenberg and others 2003), seven systems were identified in the laboratory as having reasonable performance. These systems were evaluated in the phase II outdoor field evaluations, and the results are reported here.

## Present Study

Phase II research focused on outdoor evaluation of the binder and fiber options identified as minimally acceptable and promising in the phase I evaluations. In phase II, we studied field durability and examined changes in long-term performance by quantifying the impact safety and accessibility of EWF surfaces after field exposure. Seven surface treatments and a control surface were installed in a series of outdoor test beds in Madison, Wisconsin. The binders evaluated were (a) synthetic latex emulsion, (b) low molecular weight silicone, and (c) foaming and non-foaming resilient polyurethane. Systems were evaluated over a 6-month period.

## Surfacing System Requirements

Stabilizing binders were applied on site or mixed with EWF no longer than 1 h prior to placing the test surfaces on the ground. Practical considerations evaluated were (a) cure/set time prior to surface use, (b) range of EWF moisture and temperature conditions acceptable for use, and (c) minimal emission of fumes or odors, workable exotherms, and toxic or other chemicals from the EWF-resin mixture.

The development guidelines require that a surfacing system provide impact safety and good accessibility. The Americans with Disabilities Act (ADA 1990) states that accessible surfaces shall be stable, firm, and slip-resistant. These criteria have not been defined adequately within the ADA Accessibility Guidelines for measurement on any specific surface. Currently, the only objective method suitable for assessing the firmness and stability of playground surfacing systems is the use of a rotational penetrometer (Axelson and Chesney 1999).

Impact safety is quantifiable by American Society for Testing and Materials ASTM F1292 (ASTM 1999a) and F355 (ASTM 1995). Preliminary evaluation was conducted using a portable impact test to determine the cushioning performance of the stabilizing binder. The rotational penetrometer, a portable measurement device that simulates the action of a wheelchair caster, was used to assess the level of accessibility. The portable test apparatuses and training in their use



were provided by two cooperators, Zeager Brothers, Inc. (Middletown, Pennsylvania), and Beneficial Designs, Inc. (Minden, Nevada).

The stabilized resin-EWF system needs to provide impact safety and appropriate accessibility over a number of seasons. It must retain the performance characteristics of impact energy absorption and surface resiliency. Impact safety and accessibility of the EWF surfaces were measured after a 6-month field exposure from April to October 2002 in Madison, Wisconsin. Subsequent 12-month exposure performance of each phase II EWF surface continues to be evaluated while the surfaces are in place.

The stabilized resin-EWF system needs to be nontoxic to users. Water should be able to drain from both the bonded surface and unbonded interior of the mat system. This is critical in reducing the biodeterioration potential of the wood fiber and in maintaining its cushioning behavior during subfreezing temperatures.

## Materials and Methods

### Bonded Impact/Cushioning Surfaces

Eight different test surfaces were formed with surface dimensions of 1.2 m by 1.2 m by 0.3 m deep (48 in. by 48 in.

by 12 in. deep) (Fig. 1). Seven surfaces had a top layer of bonded resin-EWF; one surface served as a full-depth control. In addition, two surfaces (A1 and E1, Fig. 1) were placed on a slope to assure drainage of the entire test surface. All surfaces were made of EWF, as defined by ASTM F2075-01 (ASTM 2001). All test surfaces were compacted to simulate the finished surface of a play area. Because there is no industry, governmental, or association definition or standard for compacting EWF, we followed playground industry installation practices.

Test surfaces for phase II (Table 1) were selected on the basis of phase I results. Any phase I system shown to have undesirable surface stability or resiliency was eliminated from phase II testing. Phase II surfaces were fabricated from EWF matched to phase I materials and obtained from a commercial supplier (licensee of Zeager Bros., Oskaloosa, Iowa). The baseline control test surface was made with only EWF.

Four bonding systems were used to fabricate phase II surfaces:

- Silicone-based, waterproofing coating (AllGuard, Dow-Corning Corp., Midland, Michigan)
- Synthetic latex (Soil-Sement, Midwest Industrial Supply, Canton, Ohio)



Figure 1—Overview of test surfaces in Madison, Wisconsin. See Table 1.

**Table 1—Surfaces evaluated in phase II tests<sup>a</sup>**

Surface	Matrix adhesive (%)	Top surface thickness (mm)
A1, A2	35 silicone	51
B	40 silicone	38
C	30 polyurethane	38
D	30 polyurethane	25 <sup>b</sup>
E1, E2	None <sup>c</sup>	None <sup>c</sup>
F	30 latex	64
G	25 latex	51 <sup>b</sup>
H	30 Vitriturf	38

<sup>a</sup>Surfaces identified in Figure 1

<sup>b</sup>Single ply of lightweight polyolefin landscaping geotextile placed between unbonded and bonded layers.

<sup>c</sup>Control.

c. Foaming polyurethane (Franklin ReactITE 8143, Franklin International, Columbus, Ohio)

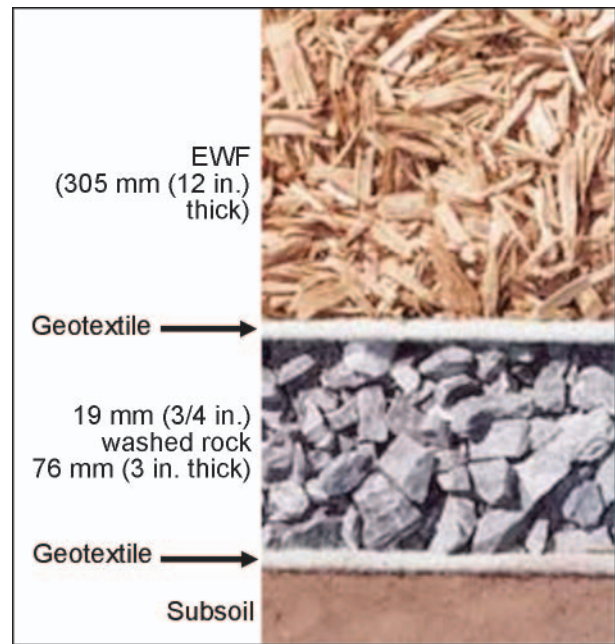
d. Non-foaming polyurethane (Vitriturf Vitricon, Polmer Plastics Corp., Hauppauge, New York)

An interfacial treatment was used for two surfaces (D and G, Table 1, Fig. 1). A 1.2- by 1.2-m (48- by 48-in.) single-ply layer of lightweight polyolefin landscaping geotextile was placed between the unbonded and bonded layers of these surfaces. The geotextile was intended to provide continuity for the thinner bonded surface layers in the event of a fracture through the entire thickness. Should this happen, the layer could be thrust from its original position and become a hazard on the remaining bonded surface.

## Installation of Test Surfaces

In accordance with general EWF design and construction practice, the full-depth surfaces were prepared to the requirements for permanent playground surfaces (Fig. 2). Installation began on February 27, 2002, and surfaces were bonded within 6 weeks. Installation proceeded as follows:

1. Excavate area 380 mm (15 in.) in depth with a minimum of 1% grade to ensure proper drainage. Remove roots, stones, and vegetation.
2. Place diversion along slope above test area to ensure no direct site drainage into surfaced area.
3. Cover entire subgrade with one layer of geotextile. Overlap courses of geotextile by 125 mm (5 in.).
4. Cover excavated surface to 75-mm (3-in.) depth with washed 18-mm (3/4-in.) stone.
5. Cover entire drainage bed with one layer of geotextile. Overlap courses of geotextile by 125 mm (5 in.).



**Figure 2—Representational cross-section of installed surfaces. Note that EWF thickness includes thickness of any stabilized EWF layer.**

6. Spread EWF to depth 1.5 times target depth and compact uniformly, resulting in density 50% greater than bulk (uncompacted) density.
7. Hand rake for smooth finished surface.
8. Install plywood retaining borders (15 mm thick by 100 mm wide, 0.6 in. thick by 4 in. wide) between each pad.
9. Prepare and install top surface<sup>1</sup>
  - a. Place EWF in 60-liter (15-gallon) mixing bin. Measure needed material by volume (1.5 × volume needed).
  - b. Measure EWF moisture content.
  - c. Measure binder as proportion of EWF dry weight.
  - d. Mix EWF and binder using a mixing paddle.
  - e. If required, place single layer of geotextile on EWF.
  - f. Immediately dump resin–EWF mixture onto target pad, spread with hand tools to even thickness, and flatten with 1.2-m by 1.2-m by 15 mm (4-ft by 4-ft by 5/8-in.) piece of plywood using firm pressure to bring cushioning pad thickness to full 0.3-m (12-in.) depth required for unbonded EWF.

<sup>1</sup> Operation requires monitoring of temperature. Most stabilizing binders require 24 h temperatures greater than 4°C (40°F) for proper curing.





Figure 3—Rotational penetrometer in use on surface A2.

## Test Procedures

### Accessibility

Periodically over the 6-month exposure and again after the 6-month impact tests, all surfaces were tested with a Beneficial Designs rotational penetrometer (Figs. 3 and 4). This device subjects the surface to a low-speed rotational bearing test meant to simulate the weight and action of a front caster wheel on a wheelchair. The procedures used were based on the draft Rehabilitation Engineering and Assistive Technology Society of North America national standard test method for the firmness and stability of ground and floor surfaces (RESNA 2000), with the exception that only one reading was recorded instead of the average of five readings. This test provides objective measures of firmness and stability of surfaces. It has been correlated to the work measurement done in ASTM F1951 (ASTM 1999b) for a wide array of surfacing and floor coverings. The test was conducted 1 week after surface installation and each month thereafter using the rotational penetrometer and protocol for assessing the bearing/rotational indentation on each surface (Axelson and Chesney 1999). Each surface was tested at a unique location around its periphery.

### Impact Attenuation

Impact tests were conducted by Doug Zeager and Ted Iljes of Zeager Brothers, Inc. (Middletown, Pennsylvania). The impact test was completed after the test surfaces had been exposed for 6 months. ASTM F 1292–99 (ASTM 1999a) test specifications and F355–95 (ASTM 1995) test methods were used at a constant test drop height of 3.05 m (10.0 ft). Three impact tests per test surface were run in sequence according to the specifications. A tripod was erected to center the impactor over each test surface (Fig. 5). Per ASTM F355, the instrumented headform was mounted on a magnetic release over the center of the surface.



Figure 4—Accessibility test with rotational penetrometer. Stability readings taken after caster wheel was rotated 360°. (a) Poor stability of surface A2 indicated by amount of silicone-coated EWF displaced by rotated caster wheel; (b) good stability of surface G.



**Figure 5—Impact attenuation test. A 4.5-kg (10-lb) hemispherical impact head was installed 3 m (10 ft) over surface D. Ted Illjes (on ladder) holds instrumentation package connected to impactor by coiled wire. Doug Zeager awaits arrival of impactor, which will be caught on first rebound from surface.**

The first impact was ignored, and the data were collected from the second and third impacts. Immediately after impact testing, EWF samples were obtained from each surface for moisture content determination.

### Moisture Content and Durability

The field systems were installed and exposed outdoors for a minimum of 6 months. The intent was to expose the test surfaces to a wide range of climatic conditions, freeze–thaw cycles, and seasonal conditions (spring rain and summer heat). Evaluation of the permeability of the surface and of the entire mat was subjective. After the 6-month exposure period, samples were taken from the surface layer and the EWF just beneath the bonded surface. These samples provided data on wood fiber moisture content and density. One test surface was excavated through its entire 0.3-m (12-in.) depth to determine the moisture profile of the resin–EWF system. A 50-mm- (2-in.-) diameter observation pipe was also inserted into this surface to monitor groundwater at the test site.

## Results and Discussion

### Accessibility

Tests of surfaces using the rotational penetrometer began 1 week after installation and were performed monthly. Measurements of firmness and stability taken with the rotational penetrometer showed a considerable amount of variation (Tables 2 and 3). Factors that may have contributed to this variation include (a) inherent variability in the physical composition of the EWF surfaces, (b) temperature-related fluctuations in resin–EWF surface properties, and (c) the fact that only single readings were taken in different locations.

In a previous study involving 39 human subjects, measurements of surface firmness and stability taken with the rotational penetrometer were shown to correlate with the amount of wheelchair work as measured according to ASTM F1951–99 (ASTM 1999b) and with the amount of energy required to ambulate or wheel across the surface (Axelson and Chesney 1999). Study participants, including wheelchair users and those who ambulated with and without mobility aids, negotiated long (400-m, 1,312-ft) test courses to determine energy expenditure. The results of this study were used to develop a classification system for levels of firmness and stability based on rotational penetrometer readings.

### Firmness

Firmness is defined as the depression of a surface when a controlled load is placed on it. The categories of firmness suggested by Axelson and Chesney (1999) are as follows:

- Firm—7.6 mm (0.3 in.) or less depression
- Moderately firm—more than 7.6 mm (0.3 in.) but less than 12.7 mm (0.5 in.) depression
- Not firm—12.7 mm (0.5 in.) or more depression

This classification system was deemed appropriate for our study. Moderately firm and moderately stable were deemed acceptable ratings for the short distances traveled. (Play areas are considered short travel distances, whereas trails and paths are considered long distances and would require the rating of firm.)

In only one instance was a surface rated as not firm, the May reading of the A2 surface (silicone binder). Most polyurethane surfaces (C, D, and H) were rated as firm. During the heat and dryness of summer, the polyurethanes as a class were rated as moderately firm. From fall until the end of testing, all three polyurethanes were rated as firm. All other surfaces, including the EWF, were consistently rated as moderately firm.



**Table 2—Surface firmness as measured by rotational penetrometer**

Surface	Surface firmness (mm) at various times						
	1 week	1 month	2 months	3 months	4 months	5 months	6 months
A2	9.7	12.2	14.2	9.9	10.2	10.7	9.9
B	10.4	9.7	11.0	9.4	9.4	9.7	10.2
C	5.1	5.1	5.1	7.4	7.9	4.6	3.8
D	6.4	5.1	4.8	10.2	7.9	6.1	4.3
E2	10.2	8.6	9.1	8.1	10.7	10.4	7.9
F	10.2	7.6	8.6	10.2	10.9	11.9	9.7
G	9.7	8.4	9.7	11.9	8.6	8.6	8.6
H	5.8	5.1	4.8	12.7	9.9	8.1	6.6

**Table 3—Surface stability as measured by rotational penetrometer**

Surface	Surface stability (mm) at various times						
	1 week	1 month	2 months	3 months	4 months	5 months	6 months
A2	15.2	262.6	258.8	23.6	24.9	20.1	24.9
B	19.8	529.1	22.6	255.8	21.3	22.4	24.1
C	5.6	6.4	5.8	8.6	9.4	6.6	5.3
D	7.6	5.6	5.6	10.2	9.1	7.6	5.8
E2	19.1	19.1	18.0	18.3	19.5	20.1	19.6
F	11.2	8.6	9.6	12.2	13.2	13.0	10.7
G	10.4	264.2	11.2	13.7	12.2	12.4	11.4
H	6.9	5.8	5.8	14.0	11.2	9.1	7.4

### Stability

Stability is defined as depression of the surface by a simulated wheelchair caster and the ability of the caster to resist further erosion or indentation as a result of 360° rotational movement. The categories of stability suggested by Axelson and Chesney (1999) are as follows:

- Stable—12.7 mm (0.5 in.) or less indentation or erosion of surface
- Moderately stable—more than 12.7 mm (0.5 in.) and less than 25.4 mm (1 in.) indentation or erosion of surface
- Not stable—more than 25.4 mm (1 in.) indentation or erosion of surface

In the 6 months of testing, the silicone surfaces (A2 and B) were rated as moderately stable or even as not stable on many occasions, whereas the other treatments were typically rated as stable (Fig. 4). The unstabilized EWF surface (E2) was consistently rated as moderately stable. In several isolated instances, the latex and non-foaming polyurethane surfaces were rated as moderately stable.

In summary, the polyurethane systems were rated as stable in nearly all tests and conditions. The latex systems performed much better than did the silicone and the control EWF surfaces. Most noteworthy is that the silicone surfaces became unstable within the first month and did not improve. The silicone-coated wood elements became disassociated from one another in the first month of the test. The silicone was

not able to bond the wood fiber in a matrix after the EWF became wet. Within 2 months, the entire surfaces of A2 and B, in which the top layer was composed of silicone-coated wood fiber, became loose (unbonded).

### Impact Attenuation

The results of impact testing are summarized in Table 4. The specifications (F1292, ASTM 1999a, and F355, ASTM F355) call for a maximum deceleration 200 g. Considering the mode of falls on playgrounds, the maximum g was chosen for the playground application to balance the cost of the cushioning surface with the expectation for injury from falls. As a relative comparison, it is useful to note that the U.S. Department of Transportation standard test for motorcycle helmets requires the helmet to bring an instrumented head-form to rest without exceeding 400 g.

All surfaces passed the existing specifications for impact attenuation of playground surfaces. The significant observation is that all the polyurethanes exhibited higher g values overall, in comparison with EWF, silicone, and latex stabilized EWF. Only the polyurethanes exceeded 100 g, but none exceeded 140 g.

A similar observation can be made for the head injury criteria (HIC). All the surfaces passed the existing HIC specifications, that is, HIC is not to exceed 1,000. The HIC value of 1,000 is generally presumed to correlate with the impact dynamics required to cause a brain concussion. Again, as



**Table 4—Results of surface impact testing in study phases I (no exposure) and II (6 months exposure) per ASTM F1292<sup>a</sup>**

Surface	Deceleration (g)				HIC			
	Drop 2		Drop 3		Drop 2		Drop 3	
	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II
A2	52	72	57	71	244	275	272	265
B	53	81	62	79	213	308	251	320
C	67	139	62	130	332	825	315	740
D	68	109	63	109	350	564	357	541
E2	68	83	76	81	274	285	307	306
F	55	85	54	90	236	339	248	387
G	56	83	60	87	312	313	324	318
H	65	103	69	101	325	493	406	472

<sup>a</sup> ASTM 1999a.

a group, the polyurethanes, both foaming and non-foaming, had the highest HIC values of all the surfaces tested. The minimum value was 472 and the highest 825. The HIC values of all other surfaces ranged from 265 to 387. We presume that an HIC of 825 will result in a higher percentage of fall injuries than will a surface with an HIC of 400.

A difference in behavior (Tukey tests,  $\alpha = 0.25$ ) differentiated the polyurethane surfaces from the latex and silicone surfaces. The impact performance of silicone, latex, and unstabilized EWF was statistically indistinguishable. We are able to state with some confidence that 6 months of aging had a significant negative influence on impact performance for all systems except the unsurfaced EWF.

## Moisture Content and Durability

Because of the in-situ nature of the tests and the size of the test surfaces, we did not have a means for nondestructively evaluating moisture content or durability of these surfacing systems. Thus, we relied on visual evaluation of the surfaces during the 6-month exposure period; moisture content samples were removed after the test period (Figs. 6 and 7). Data on surface layer density and moisture content and EWF moisture content just beneath the surface layer are shown in Table 5 and Figure 8.

Moisture content measurements indicated that the bonded surface layers, on average, were not as wet (by weight) as the E2 surface (unstabilized EWF). The measurement of moisture content is misleading because of the nonhygroscopic properties of the binder. However, the EWF under the stabilized surfaces was wetter than the bonded surface layers. This suggests that the EWF–resin surface layer retarded the drying process, which, in turn, saturated the underlying EWF.

Another representation of EWF moisture content is shown in Table 6 and Figure 9. The trendline fitted to the data of the E2 moisture profile (Fig. 9) indicates that saturation occurred at a depth of approximately 100 mm (4 in.) and continued to the drainage bed. Additional study would yield knowledge of the rate of decay under these very wet/ saturated conditions. We have no quantified model for predicting the loss (decay) of woody material under these moisture conditions. We could easily presume that the development of a stabilized resin–EWF system with reduced moisture content in the unbound EWF would result in a beneficial reduction of decay rate. This, in turn, would extend the life of stabilized EWF in situ on playground surfaces.

## Concluding Remarks

### Impact Attenuation

- All surfaces passed existing specifications for impact attenuation of playground surfaces.
- Polyurethanes exhibited higher *g* values overall (in comparison to *g* values of EWF alone, silicone-stabilized EWF, and latex-stabilized EWF) and only the polyurethanes exceeded 100, but none exceeded the maximum allowed, 200 *g*.
- All surfaces passed existing HIC specifications (HIC < 1,000); polyurethanes, both foaming and non-foaming, had the highest HIC values of all surfaces tested.
- Silicone, latex, and unstabilized EWF are not statistically distinguishable ( $\alpha = 0.05$ ) in impact performance.
- Six months of aging significantly ( $\alpha = 0.25$ ) changed the impact performance of all systems except unsurfaced (without an additive) EWF.



**Figure 6—Removal of test sample for determination of density and moisture content of surface layer and EWF beneath surface.**



**Figure 7—Archeological-type excavation for determining moisture profile of E2 surface. Note gravel at bottom of 0.3-m (12-in.) excavation.**

## Accessibility

- Firmness
  - Silicone surfaces were rated as moderately firm except for one silicone surface, which was rated as not firm.
  - Polyurethane surfaces were usually rated as firm except in summer, when the rating changed to moderately firm.
  - EWF and latex surfaces were consistently rated as moderately firm.

**Table 5—Surface layer specific gravity and moisture content and moisture content of EWF beneath surface**

Surface	Surface layer		Moisture content (%) beneath surface layer
	Dry specific gravity	Average moisture content (%)	
A2	0.265	22	131
B	0.293	48	123
C	0.438	45	160
D	0.416	35	132
E2	0.206 <sup>a</sup>	24 <sup>b</sup>	76 <sup>c</sup>
F	0.179	31	156
G	0.149	18	82
H	0.514	33	134

<sup>a</sup> Top 25 mm (1 in.).

<sup>b</sup> Top 12 mm (0.5 in.).

<sup>c</sup> Sampled at 25 mm (1 in.).

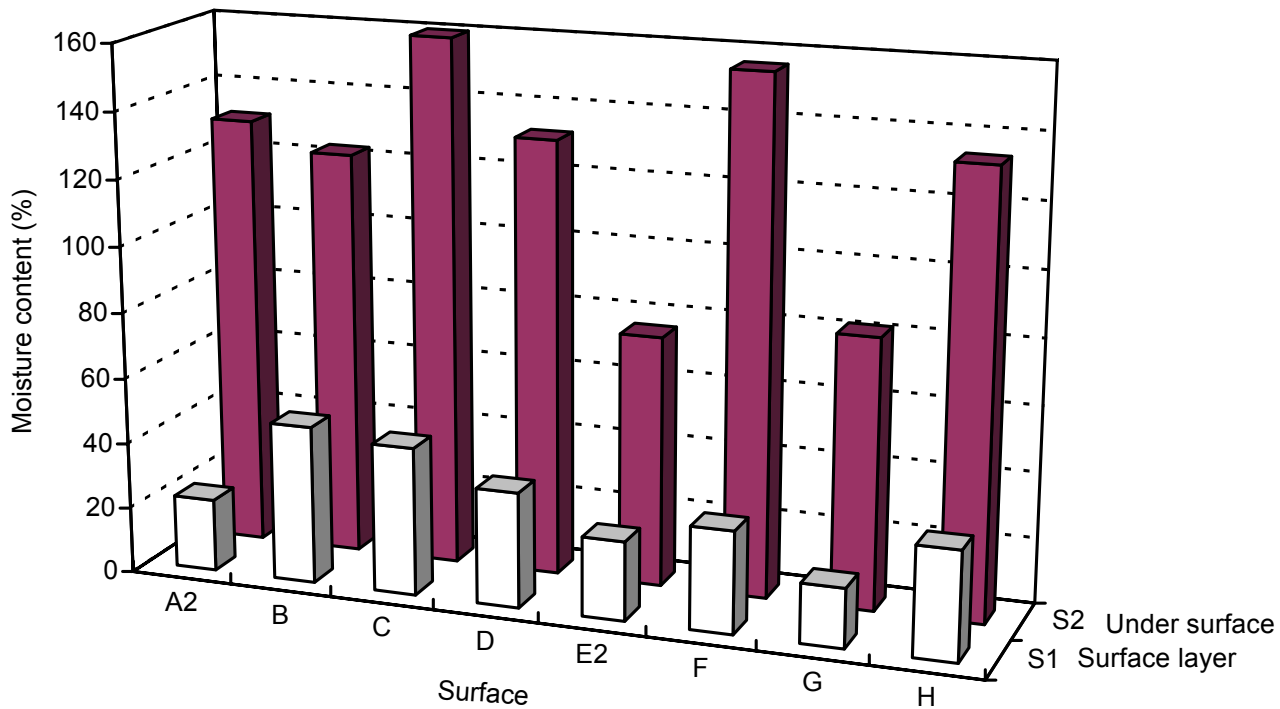
- Stability
  - Polyurethane surfaces were rated as stable in nearly all tests and conditions.
  - Silicone surfaces were rated as unstable early in the exposure period.
  - EWF and latex surfaces were consistently rated as moderately stable.

## Moisture Content and Durability

- EWF beneath the stabilized surface was significantly wetter than unsurfaced EWF.
- Stabilized surface layers retarded the drying process for the underlying EWF, saturating it.
- Additional study should focus on moisture levels and rate of decay under stabilized surfaces, which seem to exacerbate EWF wet/saturated conditions.

## Recommendations

We recommend that the next phase of development should be to install larger surfaces in a working playground to evaluate accessibility and durability. The stabilizers that have met the requirements for this next phase include the polyurethanes and latex systems. We believe it best to choose one commercially available binder for each type of adhesive system. From the standpoint of impact and accessibility performance, the polyurethane Vitriturf and the latex



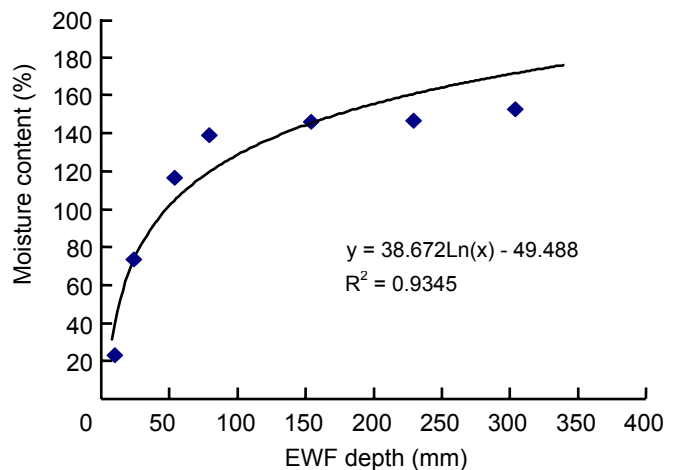
**Figure 8—Comparison of average moisture content of stabilized surface layers with moisture content of EWF immediately beneath surface.**

**Table 6—Moisture profile data for EWF**

EWF	Wet weight (g)	Dry weight (g)	Moisture content (%)	Depth (cm)
E1	23.8	13.5	76	2.5
E2	24.7	11.3	119	5.0
E3	25.8	10.7	141	7.5
E6	23.6	9.5	148	15.0
E9	25.9	10.4	149	22.5
E12	24.5	9.6	155	30.0

Soil-Sement are the best candidates. The polyurethane ReacTITE produced a hard brittle shell that hardened even more with age, which would increase the injury rate for falls on the surface. The silicone AllGuard system did not maintain its integrity adequately to bond EWF into a contiguous mat.

Before recommendations for public acceptance of any candidate resin-EWF system or systems can be made, there is a critical need for a full-scale phase III field assessment to increase our understanding of the ongoing performance and durability of the system. Using a larger pad than that used in phase II would allow five repetitions to be performed with the rotational penetrometer to reduce test variability and



**Figure 9—Profile of moisture content through EWF of surface E2 and trendline fitted through measurements.**

edge effects. At minimum, a 3- by 3-m (10- by 10-ft) surface should be installed on a working playground being accessed regularly by children. System performance and moisture and temperature profiles through the depth of the candidate EWF-resin system or systems should be carefully monitored during a 2-year field exposure. Industry leaders should be consulted to identify two configurations of each of the two binder systems.



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