Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 3(5):280-285

Using Soybean Oil to Improve the Durability of Concrete Pavements

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Abstract: One sustainable product that has shown promise in concrete application is commercially available soybean oil emulsion marketed for concrete curing. This paper describes research performed to determine what impacts soybean oil had on concrete and to evaluate the effectiveness as a curing agent. Soybean oil was tested for moisture retention and evaluated surface applied and integrally mixed. Depth of penetration was measured using several application schemes to determine effectiveness in reducing surface permeability. Deicer testing was then performed on straight cement samples and samples with 50% replacement of Portland cement with blast furnace slag. Results indicate that soybean oil substantially reduces moisture loss from fresh concrete and provides greatly improved deicer scaling resistance. For projects looking for more sustainable curing options or those located in environmentally sensitive areas where traditional curing compounds are not allowed, soybean oil may be a viable alternative.

Key words*: Concrete; Curing; Deicer scaling durability; Soybean oil; Sustainability.*

Introduction

The current socio-economic climate expects and demands sustainable construction practices. Sustainability of concrete includes not only using either “green” or recycled products, but also improving construction durability to maximize useful service life. One key component of concrete durability is providing complete curing for increased hydrated cement paste density and performance. Denser cement paste lowers permeability and helps to minimize unwanted penetration of water and aggressive ions into the cement paste matrix [1, 2]. Curing is commonly performed by applying a chemical curing compound to the surface of the fresh concrete. Common curing compounds are chlorinated-vinyl rubbers, which work well, but can have the potential for stormwater and groundwater pollution. Natural, plant-based, curing compounds have been used successfully in the past. Linseed/flaxseed oil had wide-spread use in concrete curing until modern curing chemicals were introduced in the 1970s [3]. Soybean oil, a newer curing mechanism, also has shown the potential for improved concrete curing. The particular soybean oil emulsion investigated herein is currently marketed for concrete curing and as a moisture repellent for wood decking [4].

Pervious concrete is designed with a series of interconnected voids to help infiltrate stormwater runoff. The large amount of void space means that fresh concrete mixtures are extremely susceptible to moisture evaporation and poor surface durability. The current curing method is to leave pervious concrete covered under plastic sheeting for at least 7 days. A study performed at Iowa State University investigated the effect various curing methods had on strength and surface durability of pervious concrete [5]. Results showed that mixtures cured with soybean oil had higher strength and better abrasion resistance than those cured with traditional curing chemicals.

Another preliminary investigation performed at a cement company laboratory indicated that traditional concrete mixtures coated with soybean oil had significantly less deicer scaling than the control concrete mixtures with no additional protection [6].

After a soybean oil emulsion (soybean oil, an emulsifying agent, and water) is applied to the concrete surface, oil is forced into the surface pore space of the concrete as the water evaporates. The oil prevents moisture from leaving the concrete, and the evaporating water from the emulsion elevates the surface humidity, further reducing the potential rate of moisture loss from the concrete. After the concrete has set, the soybean oil remains in the capillary void space and provides a physical barrier against deicer salt penetration. Laboratory verification of these processes has not been performed to allow soybean oil as an accepted curing and deicer resisting method for concrete. Improving the deicer scaling resistance will allow the use of concrete with higher recycled material contents without negatively impacting durability.

The objectives of this preliminary investigation were to:

- Determine if soybean oil cure meets ASTM C309 curing compound requirements for moisture retention;
- Determine the penetration depths of soybean oil into the fresh concrete and soybean oil applied to hardened concrete;
- Determine if soybean oil provides improved ASTM C 672 deicer scaling resistance; and
- Determine if integrally-mixed soybean oil impacts moisture retention, plastic shrinkage cracking, deicer scaling resistance, or permeability.

Experimental Work

Mixture Proportions

Moisture Retention (Mortar)

An ordinary Portland Cement (OPC) control mortar mixture was used for testing and had a sand to cement ratio of 2.5 to 1 and a water to cement ratio of 0.40. The cement was Type II, marketed as a Type I/II.

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Note: Submitted March 1, 2010; Revised April 30, 2010; Accepted June 22, 2010.

Table 1. Concrete Mixture Proportions.

Sample	Curing	Cement	Slag	CA	FA	w/c	AEA
			kg/m^3(*pcy*)				**(%)**
OPC-BO	none	335(564)	0(0)	878(1479)	878(1479)	0.45	0.03
OPC-BO-I	bean initial	335(564)	0(0)	878(1479	878(1479)	0.45	0.03
OPC-BO-21	bean delayed	335(564)	0 (0)	878(1479)	878(1479)	0.45	0.03
S-BO	none	167(282)	167(282)	871(1468)	871(1468)	0.45	0.03
S-BO-I	bean initial	167(282)	167(282)	871(1468)	871(1468)	0.45	0.03
S-BO-21	bean delayed	167(282)	167(282)	871(1468)	871(1468)	0.45	0.03

Table 2. Schedule of Soybean Oil Application.

Sample ID	Oil Initial	Colored Oil Initial	Oil After 21 days*s*
CBOI		X	
BOI	X		
BO21			X
BOI/21	X		X
CBOI/21		X	X

Admixture Testing (Mortar)

Soybean oil used as an integrally-mixed admixture was investigated on the control mixture. Soybean oil was dosed into the mixing water at 1.3, 3.9, and 7.8*mL/kg* (2, 6, and 12*oz/cwt*) and at 1% oil by mass of cement (22.1*ml/kg* (34*oz/cwt*)). Mixing water was adjusted to account for water in the soybean oil admixture.

Deicer Scaling (Concrete)

The ordinary Portland Cement (OPC) concrete mixture used was a six sack, 335kg/m^3 (564*pcy*) mixture with a water to cement ratio of 0.45. The cement was Type II. The coarse aggregate was a locally available limestone approved for Department of Transportation (DOT) mixtures. Sand was a non-reactive river sand. Air entraining admixture was a standard vinsol resin. The concrete mixtures used for the deicer scaling test are shown in Table 1. The soybean oil penetration test used the control concrete mixture. Samples were placed and cured according to ASTM C192 [7].

Sample Placement and Testing Procedures

Moisture Retention

Volatile content of the soybean oil emulsion was determined according to ASTM D2369 [8]. Fresh testing included moisture retention performed according to ASTM C156 [9]. Soybean oil emulsion was applied at 982m^2/L (200*sf/gallon*) and cured at 38°C (100°F) with a relative humidity of 32%. Criteria to satisfy ASTM C309 curing compound limits for moisture loss were 0.55kg/m^2 over a 72*hrs* period [10]. According to the test standard the water portion of the applied soybean oil emulsion was subtracted from the total measured moisture loss in order to isolate the moisture loss from only the mortar specimens. Observation and measurement of the plastic shrinkage cracking between the control and cured specimens was used to quantify any reduction in cracking from the soybean oil. Testing was performed on five duplicate specimens for both the soybean oil cured and control curing.

Admixture Testing

Fresh testing was performed for moisture. Hardened testing included compressive strength at 3, 7, and 28 days according to ASTM C109 [11]. Drying shrinkage was measured according to ASTM C596 [12].

Deicer Scaling

Deicer scaling resistance was performed according to ASTM C672 [13]. Two concretes were tested: (1) OPC (334kg/m^3) concrete and (2) the control mixture with 50% replacement for cement with ground granulated blast furnace slag. Samples were moist-cured for 14-days and then allowed to dry for 14-days. Deicer testing commenced 28-days after placement. Three curing regimes were studied for both concretes: (1) none, cured according to ASTM C511 [14], (2) initial soybean oil applied according to ASTM C156, and (3) delayed soybean oil applied at 21-days to drying concrete. For each mixture, 3 samples were tested.

Penetration Depth

Penetration depth of the soybean oil applied to the fresh and hardened concrete was tested visually using standard digital calipers. The samples were broken into 4 pieces and measurements were taken at 8 different locations across the 2 fractured faces of each piece. The soybean oil was applied according Table 2. Penetration depth was investigated using regular soybean oil and soybean oil with integral color for decorative concrete work. The colored soybean oil was applied initially (CBOI) and again at 21 days (CBOI/21). The traditional soybean oil depth was investigated after applying initially (BOI), after 21 days to dry concrete (BO21), and both (BOI/21).

Results and Discussion

Effect of Soybean Oil on Moisture Retention Using ASTM C156

The non-volatile content of the soybean oil emulsion was determined at 45% and consisted of the soybean oil and the emulsifying agent.

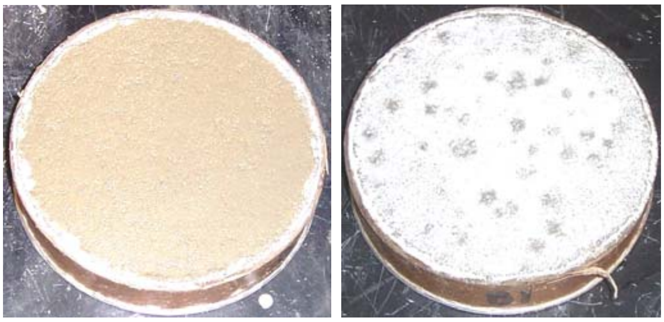

Fig. 1. Fresh Sample Without (Left) and With (Right) Soybean Oil.

Fig. 2. Samples after Moisture Loss Testing, Without (Left) and With (Right) Soybean Oil.

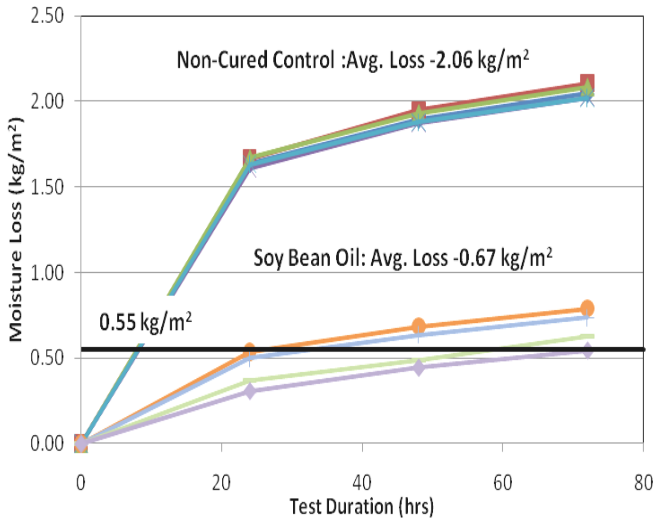

Fig. 3. Moisture Retention Test Results.

Fig. 1 shows the fresh mortar samples with and without soybean oil. All samples were observed to have unequal distribution of soybean oil (fish eyes) across the surface. Fig. 2 shows the samples after moisture loss testing. There was no observed reduction is plastic shrinkage cracking between the samples. The average results of moisture retention using soybean oil versus the control are shown in Table 3. Moisture loss of the soybean oil samples was 68% less than the control uncured samples. However, ASTM C156 criteria were not satisfied due to the curing compound not limiting moisture loss to 0.55kg/m^2 over a 72*hrs* period. Individual results for all samples are shown in Fig. 3. Variability of the soybean oil samples was higher than the uncured samples for initial and subsequent testing most likely from the uneven surface distribution.

Table 3. ASTM C156 Moisture Loss Test Results.

Sample	24-hr		48-hr		72-hr	
	(kg/m^2)	(%)	(kg/m^2)	(%)	(kg/m^2)	(%)
Non-Cured	1.64	2.5	1.91	2.9	2.06	3.1
Soybean Oil	0.43	0.6	0.56	0.8	0.67	1

Table 4. Moisture Retention Test Results.

Sample	72-hr Loss(kg/m^2)	% Loss
Control	2.06	3.10
1.3*mL/kg*(2*oz/cwt*)	1.39	2.03
3.9*mL/kg*(6*oz/cwt*)	1.26	1.95
7.8*mL/kg*(12*oz/cwt*)	1.28	1.93
1% Oil	1.24	1.92

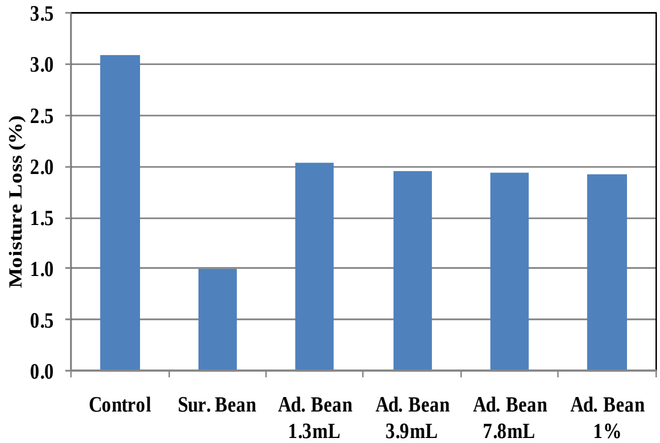

Fig. 4. Soybean Oil Admixture Moisture Retention.

Effect of Soybean Oil Used as an Admixture

After testing the moisture retention of soybean oil applied to the surface of mortar samples, additional testing was performed on integrally-mixed soybean oil. Results for the moisture retention tests using soybean oil as an admixture are shown in Table 4. All of the soybean oil samples had reduced moisture loss compared to the control mixture, but greater moisture loss than the samples with surface-applied soybean oil (Fig. 4).

Results for the compressive strength tests of the mortar with soybean oil as an admixture are shown in Table 5 and Fig. 5. Compressive strengths were all similar to the control through the 7.8*mL/kg* (12*oz/cwt*) dosage rate. Compressive strength decreased for the 1% dosage rate. The decrease is most likely due to additional air entrainment within the mortar from the surfactant in the soybean oil emulsion. Beyond the 3.9*mL/kg* (6*oz/cwt*) dosage there was no addition reduction in moisture loss (Fig. 4).

Results for the drying shrinkage tests of the mortar with soybean oil as an admixture are shown in Fig. 6 up to 28 days. All samples containing the soybean oil admixture had slightly less shrinkage than the control samples. Since the soybean oil admixture reduced moisture loss, a reduction in shrinkage was anticipated.

Table 5. Soybean Oil Admixture Compressive Strength Results.

Mix	Sample	3-d fc' *MPa* (*psi*)	7-d fc' *MPa* (*psi*)	28-d fc' *MPa* (*psi*)
M1	mortar, no oil	35.6(5160)	43.2(6270)	59.5(8630)
MBO2	1.3*mL/kg*(2*oz/cwt*)	35.2(5100)	42.8(6200)	53.6(7770)
MBO6	3.9*mL/kg*(6*oz/cwt*)	39.3(5700)	49.2(7130)	54.4(7890)
MBO12	7.8*mL/kg*(12*oz/cwt*)	39.8(5770)	43.1(6250)	60.1(8710)
MBO34	1% oil	26.7(3870)	32.8(4750)	44.3(6430)

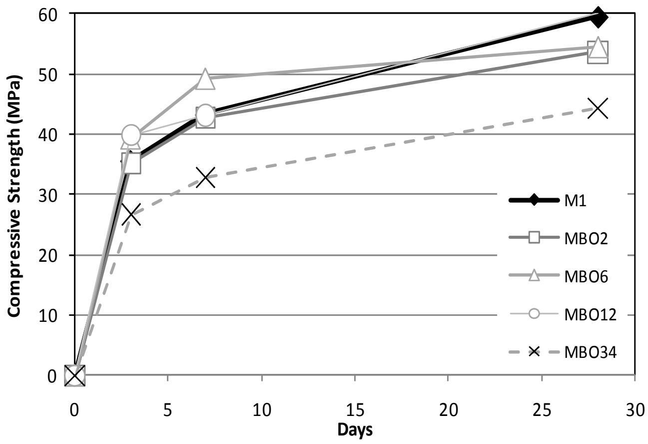

Fig. 5. Soybean Oil Admixture Compressive Strength Results.

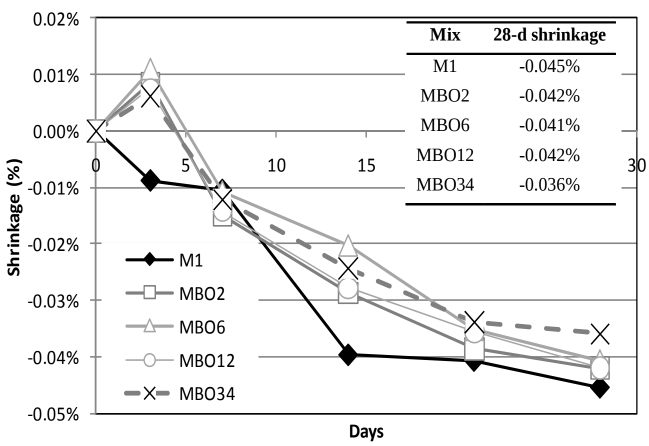

Fig. 6. Drying Shrinkage Test Results.

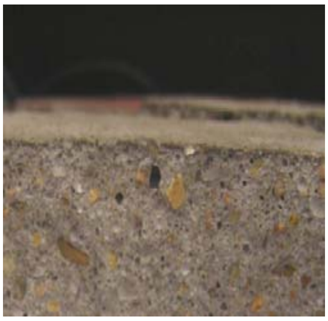

Fig. 7. BOI.

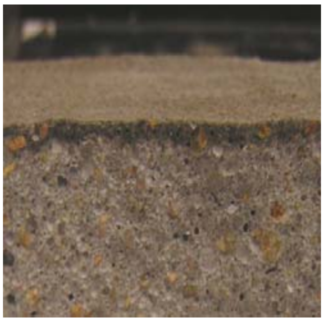

Fig. 8. BO21.

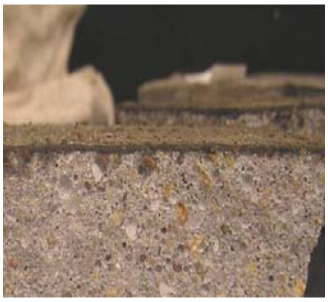

Fig. 9. BOI/21.

Fig. 10. CBOI.

Table 6. Soybean Oil Penetration Test Results.

Sample	Avg (*mm*)	Std	COV (%)
CBOI	1.34	0.21	15.81
BOI	1.68	0.2	12.19
BO21	3.16	0.23	7.03
BOI/21	1.71	0.31	18.1
CBOI/21	1.32	0.32	23.91

Table 7. Deicer Test Results.

Sample	Condition	Average Depth of Deicer Penetration (*mm*)
S-BO	5	2.7
S-BO-I	5	2.2
S-BO-21	2-3	2.9
OPC-BO	5	14.9
OPC-BO-I	5	14.5
OPC-BO-21	1	9.3

Effect of Soybean Oil on Deicer Scaling Resistance

Results for the soybean oil penetration test are shown in Table 6. The samples that had soybean oil applied after 21 days (Fig. 8) had a significantly deeper penetration compared to the samples that received either and initial coating of soybean oil (Fig. 7) or an initial coating followed by a coating at 21 days (Fig. 9). The colored soybean oil had the lowest penetration with no additional penetration observed after a second application of the regular or colored soybean oil (Fig. 10). Coloring pigment remained on the surface while the oil penetrated the concrete.

When the soybean oil emulsion is applied to fresh concrete, the concrete is comprised of cement grains, aggregate, and liquid water in suspension. Since capillary porosity has not yet developed and the specific gravity of the soybean oil is less than that of the water in the cement, the soybean oil floats on the surface with little penetration. When soybean oil is applied to hardened concrete, the soybean oil soaks into and blocks the surface porosity.

The condition of the deicer samples was rated on a scale of 1 to 5 with 1 being original or near original condition and 5 being a sample with severe deicer scaling where a significant portion of the surface concrete separated. The results for the deicer testing including the depth of deicer penetration are shown in Table 7 using silver nitrate. Measured chloride penetration for the uncured samples and sample where soybean oil was applied initially for both OPC and slag samples were less than actual. Through severe scaling a portion of the concrete surface deteriorated during testing and the depth reported in Table 7 is measured from the remaining surface. The soybean oil applied initially did not improve the deicer scaling resistance for either the OPC or 50% slag mixtures. The small

Fig. 11. OPC-BO After 5 and 50 Deicer Cycles.

Fig. 12. OPC-BO-I After 5 and 50 Deicer Cycles.

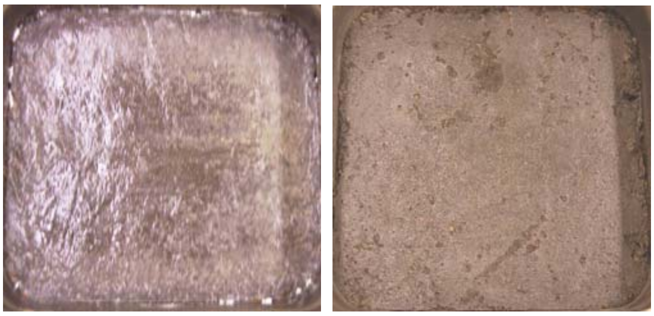

Fig. 13. OPC-BO-21 After 5 and 50 Deicer Cycles.

Fig. 14. S-BO After 5 and 50 Deicer Cycles.

penetration depth into the fresh concrete surface did not appear sufficient to protect the samples from deicer damage. However when soybean oil was applied to drying concrete at 21 days, there was a significant improvement in deicer performance for both mixtures. Figs. 11 through 16 show the deicer performance from 5 to 50 cycles. All samples appearance was the same at 0 cycles. Figs. 13 and 16 show the best performance and had application only at 21 days. Samples with soybean applied initially to the fresh concrete and then again at 21 days had deicer performance similar to application only at 21 days.

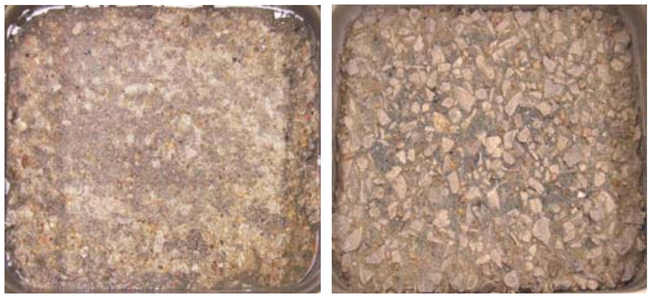

Fig. 15. S-BO-I After 5 and 50 Deicer Cycles.

Fig. 16. S-BO-21 After 5 and 50 Deicer Cycles**.**

Conclusions and Recommendations

The following is a brief summary of the testing results:

- The soybean oil emulsion provided moisture retention when surface applied or integrally-mixed. The surface application had the lowest amount of moisture loss with an average of 1.0% moisture loss compared to 3.1% for the uncured control.

  Soybean oil used as concrete admixture reduced shrinkage compared with the control samples. Compressive strengths of the admixed samples were similar to the control for the 1.3, 3.9, 7.8*mL/kg* (2, 6, and 12*oz/cwt*) samples.
- Soybean oil penetration was greatest for samples applied at 21 days to dry concrete. No additional penetration was observed for samples with applications initially and at 21 days for either traditional or colored soybean oil.
- Soybean oil applied at 21 days provided significant improvements in deicer scaling resistance for mixture containing 100% Portland cement and 50% replacement for cement with blast furnace slag. No improvements were observed for the samples with soybean oil applied initially.
- The soybean oil tested does improve moisture retention and deicer resistance. Controlled field testing is recommended to verify laboratory test results.

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