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Engineering Properties and Economics of Soil Cement Feedyard Surfacing

David B. Parker[1], Joey E. Mehlhorn[2], Michael S. Brown[1], Stefan C. Bressler[1]

[1]West Texas A&M University, Canyon, TX
[2]Middle Tennessee State University, Murfreesboro, TN

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ABSTRACT

Soil cement, a compacted mixture of soil and portland cement, has been used successfully in the past for surfacing roads and airports. Hard surfacing is being evaluated by open-lot beef cattle feedyard owners as a means to improve manure quality and increase animal performance. In this research, the engineering properties and economics of using soil cement were evaluated using Amarillo fine sandy loam, one of the most common granular soils in the Texas Panhandle region. Soil cement specimens were prepared in compaction molds to determine the optimum moisture content and cement content for compaction. Specimens were subjected to field conditions including exposure to manure for nine months, then subjected to unconfined compressive strength tests, freezing-thawing tests, and wetting-drying tests. The unconfined compressive strength of soil cement increased linearly with cement content between 5 and 20 percent (R^2=0.99). At a cement content of 7.5 percent, the specimens disintegrated when exposed to field conditions for nine months, while the specimens at 15 percent cement stayed intact. Exposure to manure for nine months did not affect unconfined compressive strength or mass lost during freezing-thawing and wetting-drying. The total cost for installing a 15 cm thick soil cement surface was estimated to be $8,110 per pen. The annual breakeven cost at a discount rate of 8% and payback period of five years was $2,031 per pen. Based on documented benefits from related research, potential returns of $5,200 per pen might be realized from improved animal performance.

Keywords: feedyard, feedlot, earthen, surface, manure, soil cement, fly ash, concrete

INTRODUCTION

Open-lot beef cattle feedyards in the Southern High Plains have traditionally been constructed with earthen surfaces in all areas except for the apron feed bunk and water trough, which are constructed of concrete. The primary reasons for using earthen pen surfaces are that they are less costly and easier to construct than hard surfaced pens. During high precipitation periods, earthen pens often become muddy as soils lose their strength. As a result, animal health and performance may suffer, and feedlot management becomes a problem.

Manure deposited in open lot feedyards is typically removed every 6 to 12 months by scraping the compacted manure from the soil surface with a front end loader or box scraper. The manure is usually applied to crop land as a nutrient source. Taking care to remove only the manure pack and not the subsurface soil increases the manure value, decreases manure handling costs and decreases pen surface construction repair costs.

There are several potential advantages to using hard surfaced pens in open lot feedyards. Manure is more easily removed from a hard surface, as there is less worry about digging into the subsoil with the front end loader. Hard surfaced pens drain faster, and are not as subject to poorly drained areas that bog the cattle down, causing wasted energy use by cattle. Because hard surfaced pens drain faster, significant odor events are less likely and less frequent. Manure scraped from a hard surfaced pen has lower ash content (mineral matter such as rocks and soil) than manure scraped from an earthen surfaced pen, making the manure more valuable to the farmer.

The major disadvantage of hard surfaced pens is the capital construction costs. Other concerns with hard surfaces include long-term durability and potential adverse effects on cattle hooves and legs. The potential benefits of hard surfaced pens continue to attract the attention of feedyard managers in the High Plains.

There are several alternatives for construction of hard feedlot surfaces: concrete, coal combustion byproducts (fly ash; bottom ash), and soil cement. The first two have been used successfully in animal feeding operations. Concrete is commonly used as a surfacing medium in dairy operations, but it is too expensive to use in a large beef cattle feedyard. Coal combustion products commonly known as fly ash, hopper ash, flue gas desulfurization (FGD) material, and fluidized bed combustor (FBC) ash have also been used in limited instances as feedlot surfacing materials. Fly ash, hopper ash, and FGD material have cementing properties and are used alone. FBC ash must be mixed with montmorillonitic clays to obtain the desired cementing properties (Greenlees et al., 1998).

In an unreplicated study, Amosson (1997) investigated the use of fly ash and hopper ash as a surfacing material in a commercial feedyard in the Texas Panhandle. Amosson found that fly ash was an adequate surfacing material requiring no repairs over the research period, but the hopper ash required many repairs and was non-economical. Amosson determined that average daily gain was slightly better on the fly ash surfaced pens (1.22 kg/d, 2.70 lb/d) as compared to the earthen surfaced pens (1.12 kg/d, 2.47 lb/d). Amosson reported costs for a 15 cm thick fly ash pen surface of \$8.28/m^2.

In another experiment in the Texas panhandle, Chirase et al. (1999) compared animal performance between fly ash surfaced pens and traditional earthen surfaced pens. Chirase found no statistical differences in animal performance between the two pen surface types, but other parameters such as feeding delivery methods and pen size may have confounded the results.

Dairies in Pennsylvania and California have been successfully paved with fly ash. Initial results suggest that cows kept on fly ash surfaces have less viral hoof infections and mastitis than cows on earthen surfaces (Suszkiw, 1999).

FGD material has been approved by the Ohio Environmental Protection Agency for use as a hard feedlot surface (Butalia and Wolfe, 1998). The FGD material can be obtained for free in Ohio, and costs are approximately evenly distributed to half for trucking and half for site work and material placement. Costs for FGD were 65% less than the costs for concrete surfacing (Butalia and Wolfe, 1998).

Greenlees et al. (1998) compared a feedyard pen stabilized with FBC ash to a pen constructed with an earthen surface. The FBC ash was mixed with low plasticity clay (CL) which was imported to the feedyard. Greenlees concluded that the soil stabilized with FBC ash was stronger than untreated soil, and the cost was one-tenth that of paving with concrete.

Soil cement is a mixture of soil and measured amounts of Portland cement and water compacted to a high density (Adaska, 1990). Granular soils are preferred because they pulverize and mix more easily than fine-grained soils, and they require less cement than fine-grained soils. Typical cement concentrations range from 4 to 16 percent by dry weight of soil (Adaska, 1990). Compaction and moisture content have a significant effect on soil cement strength, and soil cement is usually constructed at near optimum moisture content and maximum dry density as defined by ASTM Test Method D 558 (ASTM, 1996). Unconfined compressive strength is the most widely referenced property of soil cement (Adaska, 1990). Typical ranges of 28-day unconfined compressive strengths are 2750-6900 kPa (400-1000 psi) for sandy and gravelly soils, 2050-6200 kPa (300-900 psi) for silty soils, and 1700-4150 kPa (250-600 psi) for clayey soils (Adaska, 1990).

Soil cement has a variety of construction uses. It has been used successfully for road and airport stabilization projects (Adaska, 1990; PCA, 1956), for water-resource projects such as dam faces and pond liners (Hansen, 1991; Casias, 1991), for foundation stabilization under large structures (Adaska, 1990), and for wall systems in residential housing (commonly called rammed earth). However, soil cement has seen very little use in animal feeding operations.

Concrete and soil cement are sensitive to elevated sulfate concentrations. Type I Portland cement is the most common general -purpose cement used whenever sulfate hazards are absent (Lindeburg, 1989). Type V Portland cement is recommended whenever exposure to severe sulfate concentration is expected.

In this research, we evaluated the engineering properties and economics of constructing a feedyard surface using soil cement prepared with a regional soil source and Type I portland cement. The objectives of this research were to:

- Determine how water content and cement content affects soil cement unconfined compressive strength;
- Determine how weathering and manure exposure affect soil cement durability and unconfined compressive strength; and
- Determine the economic feasibility of surfacing a feedyard with soil cement.

MATERIALS AND METHODS

The soil was collected 300 m northeast of West Texas A&M University's research feedlot located 10 km east of Canyon, Texas in Randall County. Amarillo fine sandy loam (fine-loamy, mixed, thermic Aridic Paleustalfs) is one of the most common granular surface soil in the region (NRCS, 1970). The soil profile at this particular location grades coarser with depth. Because coarser soils are better for soil cement, the soil used in the experiments was collected from a depth of 15 to 90 cm. This soil was classified as sandy loam per the USDA textural classification. The soil had 23.7, 75.1, 90.3, and 98.5 percent passing the #200, #100, #60, and #40 sieves, respectively. The soil had 79.4% sand, 18.5% silt and 2.1% clay per the USDA classification. The soil was nonplastic per plastic limit and liquid limit tests (ASTM, 1996c) and was classified as SM per the Unified Soil Classification System (USCS).

Soil cement specimens were prepared by mixing the appropriate amounts of Type I Portland cement, soil, and water. Cement content was calculated as the weight of cement per weight of oven dry soil (Adaska, 1990). The soil cement was compacted in a 944 cm^3 cylindrical metal mold (Proctor mold) of dimensions 10.2 cm diameter and 11.5 cm height. Soil cement was compacted in three layers, with each layer receiving 25 blows from a 2.49 kg rammer dropped from a height of 30 cm (ASTM, 1996a). The soil cement specimens were extruded from the cylinder with a hydraulic ram.

To determine the optimum moisture content for compaction of the soil cement mixture, soil cement specimens were prepared at a variety of moisture contents for cement contents of 0, 5.0, 7.5, 10.0, 12.5, 15.0 percent. Plots of moisture content vs. density (compaction curves) were used to graphically determine the optimum moisture content and maximum dry density at each cement content.

Four specimens were prepared at optimum moisture content for each of the cement contents (5.0, 7.5, 10.0, 12.5, 15.0, and 20 percent). These specimens were cured in the laboratory at 21°C (70°F) for 28 days, then the unconfined compressive strength was measured per standard methods (ASTM, 1996b).

Additional soil cement specimens were prepared to evaluate effects of weathering and manure exposure on soil cement durability and strength. Forty-five specimens each were prepared at 15% cement content and 7.5% cement, all at optimum moisture content (10%). Fifteen of the specimens of each cement content were randomly assigned to each of three treatments. Specimens from the first treatment (TRT 1) were stored dry in the laboratory for nine months (August-May), specimens from the second treatment (TRT 2) were placed outside in plastic containers for nine months, and specimens from the third treatment (TRT 3) were placed adjacent to the TRT 2 specimens but were partially covered with manure scraped from the feedyard surface. Water was added to the plastic containers weekly. Fresh manure was placed in the TRT 3 containers every month.

After the nine month period, five specimens from each treatment and cement content were subjected to unconfined compression tests (ASTM, 1996b), wetting-drying tests (ASTM, 1996d), and freezing-thawing tests (ASTM, 1996e).

For the wetting-drying tests, specimens were subjected to 12 cycles of alternate submersion in water for five hours followed by oven-drying at 71°C for 42 hours. For the freezing-thawing tests, specimens were subjected to 12 cycles of alternate placement in a freezer at -23°C for 24 hours followed by a thawing period of 23 hours at 21°C. For both the freezing-thawing and wetting-drying tests, specimens were brushed between cycles with a wire brush on the sides and both ends.

Statistical analyses including linear regression, analysis of variance, and multiple range tests using Tukey's Honestly Significant Different (HSD) comparisons. Tukey's test sets the experiment-wise significance level at 0.05, not the comparison-wise significance level. Statistical analyses were performed using the SPSS Version 7.0 software package.

An economic analysis was performed to implement a soil cement surface for feedyards, including material cost, labor, and equipment expense. Maintenance expense and surface life were not included in the economic analysis. Cost estimates for developing a soil cement feedyard surface were estimated based on using 15% cement mixed with local fill with a total surface thickness 6 inches. Cost estimates were based on constructing pens of dimensions 45.7 m by 30.5 m, which is a common 100-head capacity pen used in commercial feedyards in the area. Equipment needs were based on recommendations from the Soil Cement Construction Handbook (PCA, 1956.). Heavy equipment identified for construction included a grader, stabilizer/reclaimer, water truck, pad roller and steel wheel roller. Cost data was compiled based on equipment rates and costs from the Rental Rate Blue Book (Primedia, 1999). Once construction cost estimates were found, investment needs and discounted break-even costs were calculated to determine the economic feasibility of using 15% soil cement on feedyard surfaces. Investors need to know the payback period associated with recovering the initial investment. Three discount rates were used to calculate break-even costs for pen construction. The three discount rates used were 6, 8, and 10 percent to provide a range of possible interest rates. Payback periods were 2, 3, 4, and 5 years. Several different years were used due to the lack of long term information available as to expected useful life of the soil cement pens.

RESULTS AND DISCUSSION

Moisture-density characteristics for the soil cement mixtures at different cement contents are presented in Table 1. Maximum dry density ranged between 1,910 to 1,990 kg/m3 (119 to 124 pcf). Optimum moisture content varied little as the cement content increased, which indicates that optimum compaction can be obtained at a moisture content of 10 percent regardless of cement content.

Cement content had a strong influence on 28-day unconfined compressive strength (Table 2). Unconfined compressive strength more than tripled from 5.0 to 20.0 percent cement content. The relationship between unconfined compressive strength and cement content was linear (R^2=0.99) (Figure 1). At the 15 percent cement content, the unconfined compressive strength was about half that of typical 20,680 kPa (3,000 psi) concrete. For comparison, the typical unconfined compressive strength of concrete is 13,790 to 41,370 kPa (2,000 to 6,000 psi) (Lindeburg, 1989).

After specimens were held for nine months, the mean unconfined compressive strength of the specimens stored in the laboratory was 4,739 kPa, as compared to 7,922 and 8,028 for the specimens stored outside exposed to water only (TRT 2) and exposed to manure and water (TRT 3), respectively (Table 3). The unconfined compressive strength of the 9-month laboratory samples was 4,739 kPa (Table 3) compared to 9,748 kPa for the 28-day breaks (Table 2). The unconfined compressive strengths of the TRT 2 and TRT 3 samples (Table 3) compared favorably with the 28-day breaks (Table 2), however, the cause of the lower shear strength in the 9-month laboratory samples is unknown.

At the 15 percent cement content, those specimens exposed to field conditions (TRT 2 and 3) exhibited 0.05 to 0.06 kg mass lost per specimen for the wetting-drying test and about 0.10 kg mass lost per specimen for the freezing-thawing test (Table 4). The mass lost from the specimens stored in the laboratory was significantly less (0.01 to 0.02 kg per specimen) than in the field, which indicates that exposure to field conditions accelerated the weathering of the soil cement. There were no significant differences between mean mass lost for TRT 2 and TRT 3, indicating that exposure to manure did not cause a difference in soil cement weathering.

All of the 7.5 percent cement specimens disintegrated after being exposed to the elements for the 9-month period. Therefore, wetting-drying and freezing-thawing tests could not be conducted on those specimens. This indicates that 7.5 percent cement is not enough for use as a feedyard surface with this soil. The 7.5 percent cement cylinders left in the laboratory for 9 months had a mean compressive strength of 2,648 kPa (Table 3), which is considerably lower than the 28-day compressive strength of 4,423 kPa (Table 2). The exact cause of the lower strengths is unknown. Though the soil collected for the soil cement specimens in Table 2 and Table 3 was collected from within a 3-m area for both, the soil was collected at different times so it is possible that soil variation could haved been a factor in the variability in compressive strengths.

Greenlees et al. (1998) cited a required soil bearing pressure of 136 kPa (20 psi) for a typical 680 kg beef animal, corresponding to an unconfined compressive strength of 36 kPa. Greenlees also stated that an animal in motion would require about twice the strength, or 72 kPa unconfined compressive strength. As soil increases in moisture content, its shear strength decreases correspondingly until eventually the soil is too soft to support the animal, and the animal sinks in the mud. At the 15 percent cement content, the unconfined compressive strengths of the soil cement were more than adequate for supporting animals.

Of more importance to the adequacy of a pen surface is the capability to withstand loading from heavy equipment. Manure is removed from open lot feedyards about every six months using wheel front-end-loaders (Caterpillar 950G, Case 821C, John Deere 624G and equivalent sizes). The loaders have operating weights of about 13,600 to 17,200 kg (30,000 to 38,000 lbs), with typical tire pressures of about 517 kPa (75 psi). At the 15 percent cement content, the unconfined compressive strengths of the soil cement were 4,739 to 9,748 kPa, which is considerably greater than the pressures exerted by the heavy equipment. Of equal importance to the integrity of the soil cement is the bearing capacity of the soil below the soil cement. If the soil beneath the soil cement is not compacted adequately, a bearing capacity failure could occur in the subsoil, resulting in cracking and ultimate failure of the soil cement surface above.

ECONOMICS

Material costs for constructing the 45.7 m x 30.5 m pens were estimated to be $4.76 per square meter, with labor/equipment costs of $1.06 per square meter. For a soil cement thickness of 15 cm, the total construction cost was estimated at $5.82 per square meter (Table 5), which is considerably less than costs for fly ash ($8.28/m^2) and concrete ($29.90/m^2). These preliminary estimates indicate that using soil cement pen surfacing will cost approximately $8,110 per pen.

At a payback period of 5 years and discount rate of 8%, the breakeven cost per pen is $2,031 per year. Annual discounted breakeven costs for discount rates of 6, 8, and 10% and payback periods of 2, 3, 4, and 5 years are shown in Table 6.

Amosson (1997) reported a 9% increase in average daily gain for beef cattle on fly ash-surfaced pens compared to earthen-surfaced pens. However, because the difference was not statistically significant, the applicability of this number to economic projections is inappropriate at this time. The National Research Council (1981) suggests that feedlot cattle housed in pens with 10 to 20 cm of mud would require between 5 and 15% more feed per unit of gain than cattle housed in pens with a dry surface. However, a hard surfaced pen would be expected to accommodate a greater density of animals compared to traditional soil surface feedlot pens. Although few data are available, studies by Prawl et al. (1998) suggest that the combined effects of increased animal density, a cement pen surface, and partial shelter can decrease feed required per unit of gain by approximately 18%. Assuming diet costs of $0.11/kg, no independent effect of partial shelter, and a similar response for soil cement compared with a concrete surface, potential returns of about $26 per animal, or about $5200 per pen, might be realized from improved animal performance. This potential benefit greatly exceeds the five year breakeven cost of $1,718 per pen, thus it appears that hard surfaced pens could have an application in beef cattle feedlots. Actual economic advantage of surfaced pens will depend on savings in maintenance, construction costs, surface life, manure quality, and hidden marketing advantages.

CONCLUSIONS

The following conclusions were drawn from this research:

1. The optimum moisture content to achieve maximum dry density during compaction was 10 percent and varied little with cement content. A linear relationship was observed between unconfined compressive strength and cement content. The unconfined compressive strength of the soil cement with 15 percent cement content was about 8,000 kPa, which compares to 20,000 kPa (3,000 psi) for typical concrete slabs.

2. Soil cement specimens with 7.5% cement content weathered excessively when exposed for 9 months, while those with 15% cement content withstood the weathering. Specimens exposed to manure weathered the same as those not exposed to manure. A cement content of 15% is recommended when preparing soil cement using this soil.

3. The total cost for installing a 15 cm thick soil cement surface was estimated to be \$5.82 per square meter, or \$8,110 per pen, which compares favorably to costs for fly ash surfacing (\$8.28/m^2) and concrete (\$29.90/m^2). Potential returns from increased animal performance appear to outweigh costs of building hard surfaced pens, however, benefits in animal performance, pen maintenance, and manure quality should be verified through future field studies.

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Table 1. Moisture-density characteristics of soil cement mixtures.

Cement Content (%)	Optimum Moisture Content (%)	Maximum Dry Density (kg/m^3)	Dry Density at -3% of Optimum MC (kg/m^3)	Dry Density at +3% of Optimum MC (kg/m^3)
0.0	10	1950	1840	1840
5.0	11	1940	1720	1810
7.5	10	1990	1800	1860
10.0	11	1910	1730	1790
12.5	10	1920	1760	1860
15.0	10	1920	1840	1810

MC = moisture content

Table 2. Unconfined 28-day compressive strengths of lab-cured soil cement specimens at six cement contents.

	Unconfined Compressive Strength	
Cement Content (%)	Mean (kPa)	Standard Deviation (kPa)
5.0	2937 a	386
7.5	4423 b	374
10.0	5759 c	377
12.5	7738 d	548
15.0	9748 e	382
20.0	12235 f	1971

Means with different letters are significantly different at α=0.05 (Tukey's test).

Table 3. Characteristics of soil cement specimens exposed to three treatments at cement contents of 7.5 and 15.0 percent.

	Mean Specimen Mass		Unconfined Compressive Strength	
	Initial (kg)	Final (kg)	Mean (kPa)	Std Dev (kPa)
15.0 Percent Cement Content				
Treatment 1: Stored in lab for 9 months	1.86 f	1.78 cd	4739 a	1543
Treatment 2: Exposed to weather for 9 months	1.87 f	1.78 de	7922 b	1793
Treatment 3: Exposed to weather/manure for 9 mo.	1.86 ef	1.84 def	8028 b	2107
7.5 Percent Cement Content				
Treatment 1: Stored in lab for 9 months	1.77 cd	1.70 c	2648 a	657
Treatment 2: Exposed to weather for 9 months	1.77 cd	1.45 a	NA	NA
Treatment 3: Exposed to weather/manure for 9 mo.	1.80 def	1.55 b	NA	NA

Mean initial and final specimen masses with different letters are significantly different at α=0.05 (Tukey's test).
Mean unconfined compressive strengths with different letters are significantly different at α=0.05 (Tukey's test).
NA = Not analyzed, samples disintegrated after nine months in the field.

Table 4. Results of wetting-drying and freezing-thawing tests on soil cement specimens at 15% cement content, showing mass of specimen lost during wetting-drying and freezing-thawing tests.

	Wetting-Drying Test			Freezing-Thawing Test		
	Initial Mass (kg)	Mean Mass Lost (kg)	Std Dev Mass Lost	Initial Mass (kg)	Mean Mass Lost (kg)	Std Dev Mass Lost
Treatment 1: Stored in dry lab for 9 months	1.80	0.01 a	0.004	1.78	0.02 a	0.013
Treatment 2: Exposed to weather for 9 months	1.78	0.06 b	0.020	1.74	0.10 a	0.036
Treatment 3: Exposed to weather/manure for 9 mo.	1.81	0.05 b	0.005	1.82	0.10 a	0.112

Means with different letters within a single column are significantly different at α=0.05 (Tukey's test).

Table 5. Pen cost estimates using 15% soil cement as a feedyard surface.

Material Cost *†	Labor & Equip†	Total Cost	Total Cost Per Pen‡
$/m^2	$/m^2	$/m^2	$/pen
4.76	1.06	5.82	$8,110

* Material charge includes hauling expense.
† Soil cement thickness equals 15 cm.
‡ Pen size equals 45.7 m x 30.5 m.

Table 6. Annual discounted breakeven costs for soil cement as a feedyard surface.

Discount Rate	Initial Cost ($)	2 Years ($)	3 Years ($)	4 Years ($)	5 Years ($)
6 %	$8,110	$4,423	$3,034	$2,340	$1,925
8 %	$8,110	$4,548	$3,147	$2,449	$2,031
10 %	$8,110	$4,673	$3,261	$2,558	$2,139

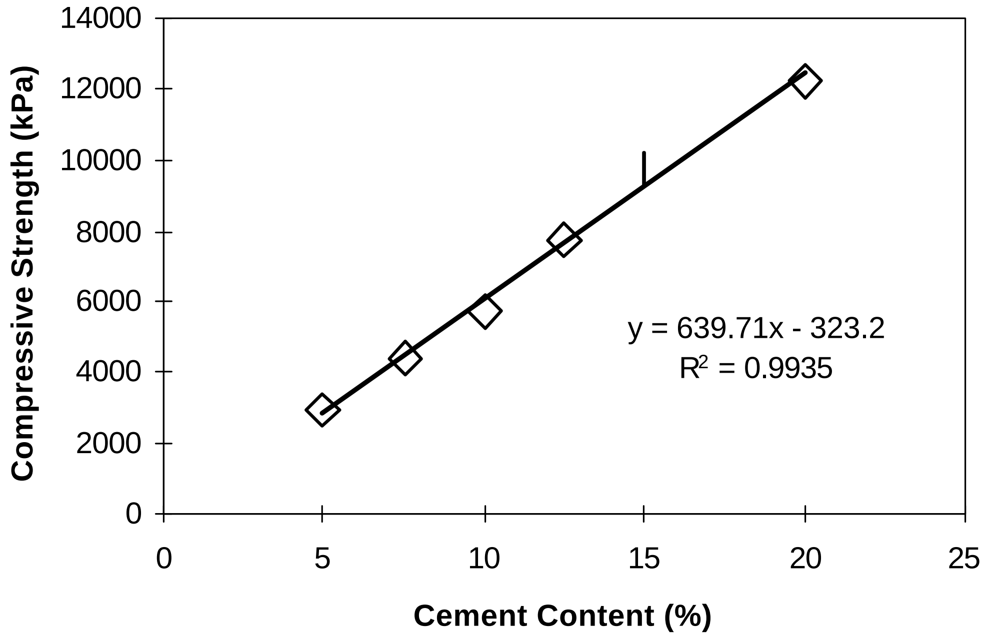

Figure 1. Variation of unconfined compressive strength with cement content of soil-cement specimens compacted at the optimum moisture content of 10%. Data points represent averages of n=4 specimens at each moisture content.