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16. Abstract

This study examined the repeatability of the International Slurry Surfacing Association (ISSA) mixture design tests by evaluating the variability of the test results obtained. Consistencies between material combinations and within a given material formulation were evaluated. The repeatability of the tests using materials falling within current micro-surfacing specifications was obtained. Material compositions were varied, and the responses for the various tests were examined to identify any definite trends. This process revealed more about the behavior of materials used in typical micro-surfacing mixtures. The establishment of the repeatability of these tests and the observation of the impact of material variation is an initial investigation that provides a foundation for future micro-surfacing research.

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EVALUATION OF MICRO-SURFACING MIXTURE DESIGN PROCEDURES AND THE EFFECTS OF MATERIAL VARIATION ON THE TEST RESPONSES

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IMPLEMENTATION STATEMENT

This project developed specifications, mixture design procedures, mixture verification procedures, usage guidelines, and quality assurance requirements for micro-surfacing treatments to be applied to highway pavements. The mixture design procedure tests were evaluated in the laboratory and modified as needed. Test protocols were developed for each test. Mixture designs and quality assurance procedures were tested in the field. Quality assurance checklists were developed for use by field personnel.

This report describes an evaluation of mixture design tests to determine their suitability for use by the Texas Department of Transportation. The tests selected will be useful in mixture design verification by the Department. Those not selected will prevent use of tests that are not repeatable, and that will not give reasonable data for mixture design.

DISCLAIMERS

The contents of this report reflects the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

Metric units are used in this report. In most cases, these units are followed by equivalent English units. When the laboratory test results were traditionally reported in metric units, they are not followed by English units. In some cases the traditional units were mixed metric and English, and these are preceded by equivalent metric units.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure | Page

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure Page

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

SUMMARY

This study examines statistically the repeatability of the International Slurry Surfacing Association (ISSA) mixture design tests by estimating the h and k consistency statistics for the test results obtained. An idea of the repeatability of the tests using materials falling within current micro-surfacing specifications is obtained. Material quantities are varied, and the test responses for the various tests are observed for any definite trends. This process throws more light on the behavior of materials used in typical micro-surfacing mixtures. The establishment of the repeatability of the tests and the observation of the impact of material variation is an initial investigation that provides a foundation for future micro-surfacing research.

CHAPTER 1
INTRODUCTION

Micro-surfacing is a polymer modified, quick setting, cold slurry paving system. This high performance, thin slurry surfacing consists of a densely graded fine aggregate, polymer-modified asphalt cement, water, mineral fillers and special emulsifiers called additives (1). The polymer modified asphalt cement allows the material to remain stable even when applied in multi-stone thickness (2). The emulsifier is a proprietary product. Manufacturers of these emulsifiers license contractors to place their particular product. It is a cold mixed slurry mixture. The asphalt emulsion and water provide fluidity to the system. Chemical processes not fully understood harden the mixture. Because heat is not used in the construction process, there is little initial hardening of the binder (3).

Each mixture formulation is a chemical system and is affected by many variables such as the different combinations of aggregates, class of emulsifiers and bitumen from various suppliers (4). A theoretical approach to evaluate the systems is difficult. An empirical approach to subject laboratory samples to simulated field tests is a more realistic approach.

Most mixture designs are prepared and provided by the contractor. The most widely used tests are those recommended by the International Slurry Surfacing Association (ISSA). These tests are documented in the ISSA design technical bulletins January, 1991 (5). The ISSA mix design tests include wet and cured cohesion (ISSA TB 139), loaded wheel (ISSA TB 109), wet track abrasion (ISSA TB 100), and compatibility classification such as Schulze-Breuer and Ruck procedures (ISSA TB 144).

The wet track abrasion test (WTAT) (ISSA TB 100) is used to determine the minimum asphalt content. This test simulates the wet abrasive conditions of a vehicle cornering and braking. A 1-hour and 6-day soak period are recommended. A maximum value of 807 g/m^2 (75 g/ft^2) abrasion loss is recommended by the ISSA after the 6-day soak period. This maximum value is the amount of micro-surfacing material lost per unit area during the test. The value is correlated to field performance (3). There is only a correlation for 6 mm (¼ in) thicknesses and 0/4.75 mm (0/#4) gradations, i.e., gradations that have no material retained on the 4.75 mm (#4) sieve.

The loaded wheel test (LWT) (ISSA TB 109) is currently used to determine the maximum asphalt content. The maximum asphalt content is attained when the sand adhesion value is 538 g/m^2 (50 g/ft^2). The sample is preconditioned with 1000 cycles of the 56.82 kg (125 lb) loaded wheel. A measured quantity of hot sand is placed on the sample and 100 cycles of the wheel are applied. The amount of sand that adheres to the sample is measured. A conversion factor is then applied to the weight increase due to adhered sand. The factor converts the weight of adhered sand to grams per square meter of the sample. The value obtained is termed the sand adhesion. It is reported that when the sand adhesion is below 538 g/m^2 (50 g/ft^2) flushing should not occur (4).

Objectives

The guidelines for micro-surfacing mixture design outlined in the International Slurry Surfacing Association Design Technical Bulletin (January 1991) (5) form the basis of the part of the study described in this report.

The objectives of this study are:

1. To examine the repeatability of the test results obtained from the four mixture design tests proposed by the ISSA, including:

    - ISSA No. 139 : Method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics,

    - ISSA No. 100 : Method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak,

    - ISSA No. 109 : Method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion, and

    - ISSA No. 144 : Method for the classification of aggregate filler-bitumen compatibility by Schulze-Breuer and Ruck procedures; and

2. To examine the effects of variations in mineral filler portland cement, water, and additive on the test results of specific micro-surfacing formulations.

CHAPTER 2
DESCRIPTION OF ISSA MIXTURE DESIGN TESTS EVALUATED

GENERAL

The International Slurry Surfacing Association design technical bulletin (January 1991) (5) contains guidelines for the laboratory evaluation of micro-surfacing mixture designs. The tests examined include:

- ISSA No. 139 : Method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics,
- ISSA No. 100 : Method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak,
- ISSA No. 109 : Method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion, and
- ISSA No. 144 : Method for the classification of aggregate filler-bitumen compatibility by Schulze-Breuer and Ruck procedures.

TEST PROCEDURES EVALUATED

Technical descriptions of the test apparatus and procedures used in this study of micro-surfacing mixture design are described in the following paragraphs. Generally, apparatus and materials are the same as those in the International Slurry Surfacing Association design technical bulletin January 1991 (5), but the sample preparation and testing procedures differ slightly.

Modified Cohesion Test

The cohesion test is used to establish baseline formulations of emulsion, mineral filler, water (distilled) and aggregate suitable for further testing. Selection of appropriate filler contents and water contents is made based on results obtained after 30 and 60 minutes of curing at room temperature, 25°C (77°F) and 24 hours curing in a 60°C (140°F) oven. The minimum values required are 12 kilogram-centimeters for the 30 minutes test, 20 kg-cm for 60 minutes and 24 kg-cm for 24 hours cured cohesion. Figure 1 shows the modified cohesion tester.

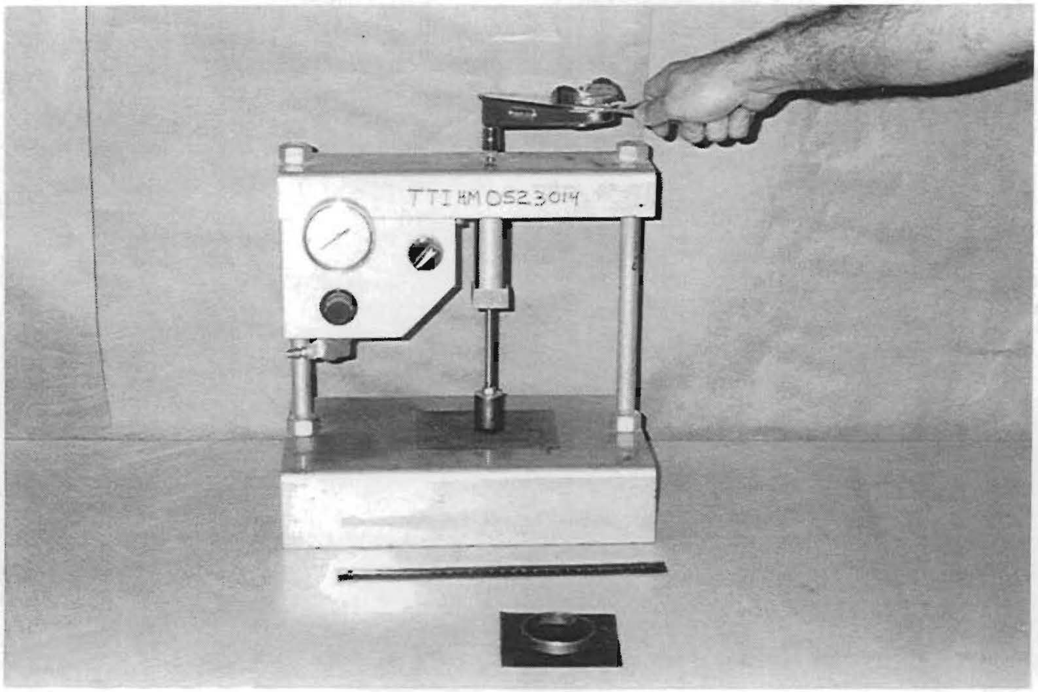

Figure 1. Modified cohesion test device

Apparatus and Materials

1. Modified cohesion tester, similar to the ASTM D 3910-80 but modified thus:

    a. 28.5 mm (1⅛ in) double rod air cylinder with 8 mm (5/16 in) rods and 75 mm (3 in) stroke,
    b. 6 x 28.5 mm (¼ in x 1⅛ in) 60 durometer neoprene rubber foot,
    c. Air pressure regulator with a variable down stream bleed valve with exhaust port regulating valves,
    d. Four-way directional control valve with exhaust port regulating valves,
    e. Air pressure gauge with a 0 to 700 k Pa (0 to 100 psi) pressure gauge,
    f. 700 K Pa (100 psi) air supply, and
    g. Torque meter capable of measuring and marking at least 35 kilogram- centimeters (kg-cm) torque.

2. A supply of 10 cm^2, 7 kg (15 lb) saturated roofing felt to be used as specimen mounting pads.

3. Specimen molds 6 mm x 60 mm diameter.

4. ASTM E-11 sieves 4.75 mm and 0.75 mm.

5. Plastic 0.6 liter (20 ounce) cup for mixing.

6. Steel spatula for mixing and for scraping off neoprene foot.

7. A scale capable of weighing at least 600 g to a hundredth of a gram accuracy.

8. Wash bottle with a very fine spout.

9. Oven set at 60°C (140°F).

10. For Calibration

    a. 20-30 mesh standard ASTM C-190 Ottawa Sand,
    b. 220 grit silicon carbide 3-M™ brand sand paper,
    c. 100 grit silicon carbide Carborundum™ brand sand paper, and
    d. Load cell to periodically check the cohesion meter pressure.

Sample Preparation and Testing Procedure

Aggregate meeting the Texas Department of Transportation (TxDOT) grade II gradations were screened over a 4.75 mm (No. 4) sieve. Material not passing the 4.75 mm sieve was discarded. Three kilograms of aggregate were split and quartered using a riffle box. One hundred grams of aggregate were carefully measured into a plastic cup. The appropriate amount of cement or mineral filler used was carefully measured out. Whenever the mineral filler appeared slightly lumpy, it was sieved through a 0.075 mm (No. 200) sieve prior to use. The mold was placed on the center of the felt pad, the corners of the pad having already been marked with the designated information, such as the amount of water, cement, and emulsion. Mineral filler was then added to the aggregate in the cup and thoroughly dry mixed for 10 seconds by stirring vigorously with a steel spatula. The aggregate and filler mixture was placed on the scale. After zeroing the scale, the desired amount of distilled water was added. The mixture was then thoroughly mixed for 10 seconds using a steel spatula. Asphalt emulsion was added after the scale had been zeroed. Accepted scale tolerance was 0.01 gram. The mixture was stirred rapidly for 5 to 10 seconds until uniformly mixed. The mixture was then poured to one side of the mold. Using a steel spatula, immediately, the mixture was spread to cover the mold, in a minimum number of strokes leaving a flush surface. The mold was then gently lifted off in an upright manner with the fingers, so that the sample was not disturbed. A timer was used to measure the time for testing, either 30 minutes or 60 minutes. The 24-hour cured samples were placed in a 60°C (140°F) oven for 24 hours. Samples were cooled for two to five minutes and then tested in the manner as described in the following paragraph.

The sample was centered under the neoprene foot. The torque wrench was set to zero and placed on the top of the cylinder rod. The vertical load was applied for five seconds. Then the torque wrench was twisted in a smooth, firm, horizontal motion through a 90° arc within 0.5 to 0.7 seconds. The cohesion reading on the wrench was recorded as the cohesion of that mixture formulation at a specific time.

Wet Track Abrasion Test

Wet track abrasion test is a field simulation test to establish the minimum asphalt emulsion content necessary to prevent excessive raveling. Two tests were conducted after curing the samples. The first test was performed after one hour of soaking in water and the second after six days of soaking to determine susceptibility to long-term moisture exposure. Figure 2 shows the wet track abrasion machine.

Apparatus and Materials

1. A Hobart N-50 mixer, equipped with a 2.27 kg abrasion head, quick clamp mounting plate and 300 mm depth flat bottom metal pan fitted with a stable pan supporting device.

2. Rust-proof round bottom bowl for use as sample mixer.

3. A scale capable of weighing 5000 grams to within 0.1 gram.

4. Fourteen kg (30 lb) roofing felt squares 300 mm x 300 mm.

5. Twenty-five mm diameter and 450 mm long, smooth, planed hardwood dowels.

6. Rust resistant metal flat surfaced specified mold, depth 6.35 mm and diameter 254 mm.

7. Forced draft oven set at 60°C.

8. Open air, rubber tanks.

9. 127 mm length reinforced rubber covered hose. (Parker 290 Ozex general purpose hose) with 19 mm internal diameter and 6.25 mm wall thickness.

Sample Preparation and Testing Procedure

Sample preparation was essentially the same as that for cohesion testing except that 700 grams of dried aggregate were used in sample preparation. As such, the material quotation for each formulation which was based on 100 grams of aggregate was multiplied

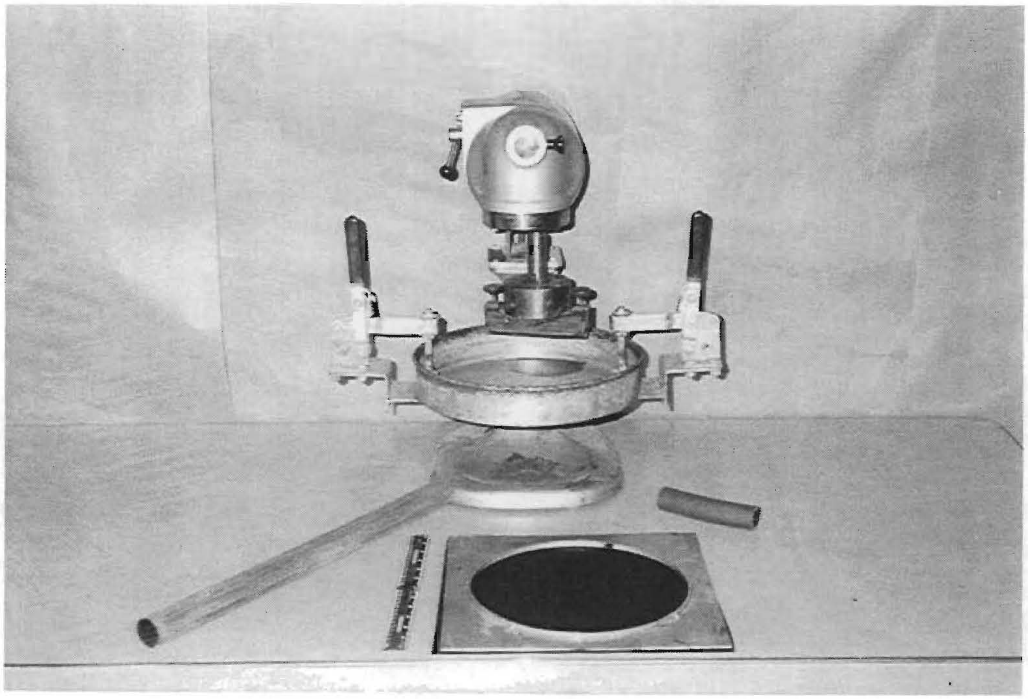

Figure 2. Wet track abrasion test device

by seven. The sample was thoroughly mixed for not more than ten seconds in a round bottom steel bowl using a long spoon. The specimen mold was centered on the square roofing felt pad. The micro-surfacing slurry was then rapidly poured out onto the felt pad, over about half the space from one edge to cover. It is important that the mixture is squeegeed in one direction only and worked over only once with a the wooden dowel using a sawing motion. Segregation occurred if worked over more than once and emulsion bled from beneath the mold. The whole operation must be completed in less than 45 seconds. After the emulsion broke, the mold was removed. The molded sample was then placed in a 60°C (140°F) oven to dry to a constant weight. About fifteen hours was required to dry the sample to a constant weight.

The dried samples were removed from the oven and allowed to cool for ten minutes. After cutting off the edges of felt pad, the sample was weighed and the weight recorded. The sample was then immersed in a water bath at room temperature of 25°C (77°F) for 60 minutes or six days.

At the end of the soaking period, the sample was placed in the flat bottom pan of the abrasion tester and covered with five to six millimeters of distilled water at room temperature. The sample was then carefully clamped to the pan. If this was not done carefully, some aggregate was lost.

An unused side of the abrasion head (water hose) was brought into contact with the sample by lowering the head. The head at this stage was freely resting on sample surface. The timer was set for five minutes and fifteen seconds. The mixing speed was adjusted to position one and allowed to abrade the sample for the set time. For each test, a fresh side of the hose was exposed. Each hose piece was used a maximum of four times.

The tested sample was removed from the pan, and the surface was flushed with slow-running room temperature distilled water. It was then dried to a constant weight in a 60°C (140°F) oven, and the new weight was recorded.

Loaded Wheel Test

The loaded wheel test is a field simulation to investigate resistance to flushing under heavy load. It serves as a measure to determine the maximum amount of binder the mixture can withstand, by measuring how much fine sand adheres to a preconditioned sample. Figure 3 shows the loaded wheel tester.

<u>Apparatus and Materials</u>

1. A wheel testing machine designed to the specifications given in the ISSA technical bulletin No. 109, January 1991 (5).

2. Specimen mold 9.5 mm thick x 75 mm x 406 mm (0.375 in x 3 in x 16 in) outside, and 50 mm x 80 mm (2 in x 15 in) inside dimensions.

3. Steel specimen mounting plates 0.6 mm (0.024 in) galvanized steel 75 mm x 406 mm (3 in x 16 in).

4. 56.7 kg (125 lb) weight.

5. Steel sand frame, 5 mm x 63.5 mm x 380 mm, (0.188 in x 2.5 in x 15 in) outside and 37.5 mm x 360 mm (1.5 in x 14 in) inside dimensions; one side of the frame should be completely lined with 12.5 mm x 12.5 mm (½ in x ½ in) adhesive backed foam rubber insulation and hold down clamps.

6. Hard wooden dowel 150 mm (6 in) long and 25 mm (1 in) diameter.

Figure 3. Loaded wheel test device

Sample Preparation and Testing Procedure

Samples were prepared in the same manner as for wet track abrasion, except only 300 grams of aggregate were used. A short, wooden dowel was used to screed off excess material using a sawing motion. The sample frame was rigidly held in one hand while this was being done. The sample was cured to a constant weight for a minimum of fifteen hours in a 60°C (140°F) forced air oven before testing. After the sample had cured and cooled to room temperature, it was firmly clamped to the frame and exposed to the passage of 1000 cycles of the 56.7 kg (125 lb) loaded wheel. A properly calibrated machine should achieve this in approximately 22.5 minutes. The weight of this compacted sample was recorded. The sample was then firmly clamped together with the steel sand frame. Two hundred grams of fine Ottawa sand (ASTM Designation C-109 graded standard) heated to 82°C (180°F) was uniformly spread over the sample surface that appears within the frame. A preheated metal strip (heated for twenty minutes in the 82°C (180°F), oven) was placed over the sand covered sample surface. This metal strip has dimensions that allows it to fit snugly into the sand frame. The wheel was immediately placed on the sample, 56.7 kg (125 lb) loaded, and 100 cycles applied.

The sample together with the sand frame, closely held together, was then removed. Loose sand was poured out, and the sand frame was released. Gently but firmly, the sample was then tapped uniformly from one end to the other and back in twenty light strokes. The sample weight was then recorded. The difference in weight is the adhered sand.

The Schulze-Breuer and Ruck Procedures

The Schulze-Breuer and Ruck procedures define a method for determining aggregate filler and bitumen compatibility. The test method as outlined in the ISSA design bulletin (5) TB-144 was not followed precisely. TB-144 specifies that the test be performed with 8.125 percent pure asphalt content of the emulsion. As specified in the bulletin, the test can be performed by regrading the aggregate to a specific gradation or cutting off all material that does not pass the No. 10 sieve, and then using the natural gradation obtained. It is also suggested that about 50 grams of water be used for every 200 grams of aggregate. In our test, the aggregate was not re-graded and the same amount of water and mineral filler as specified in the micro-surfacing formulation was utilized. This was done to not only investigate consistency in results, but also to investigate the aggregate and bitumen compatibility at asphalt contents less or greater than 8.125 percent pure asphalt. Figure 4 shows the Schulze-Breuer abrasion tester.

Apparatus and Materials

1. Rust proof large steel mixing bowls (should be large enough to contain a 1000 grams of aggregate.)

2. Scale sensitive to 0.001 grams.

3. Forced draft oven set at 60°C (140°F).

4. Pill molds consisting of a base, a case 30 mm (1.18 in) inside diameter by 70 mm (2.76 in) height and 29 mm (1.14 in) diameter ram.

5. Constant force ram capable of exerting a constant force of 1000 kg (2200 lb).

6. Shuttle cylinders consisting of acrylic tubes, 60 mm (2.36 in) inside diameter containing 1100 ml volume and closed with tight metal caps at each end, one of which is readily removable.

7. Abrasion machine, holds eight cylinders as described previously. Rotates such cylinders end for end about a central axis at 20 RPM.

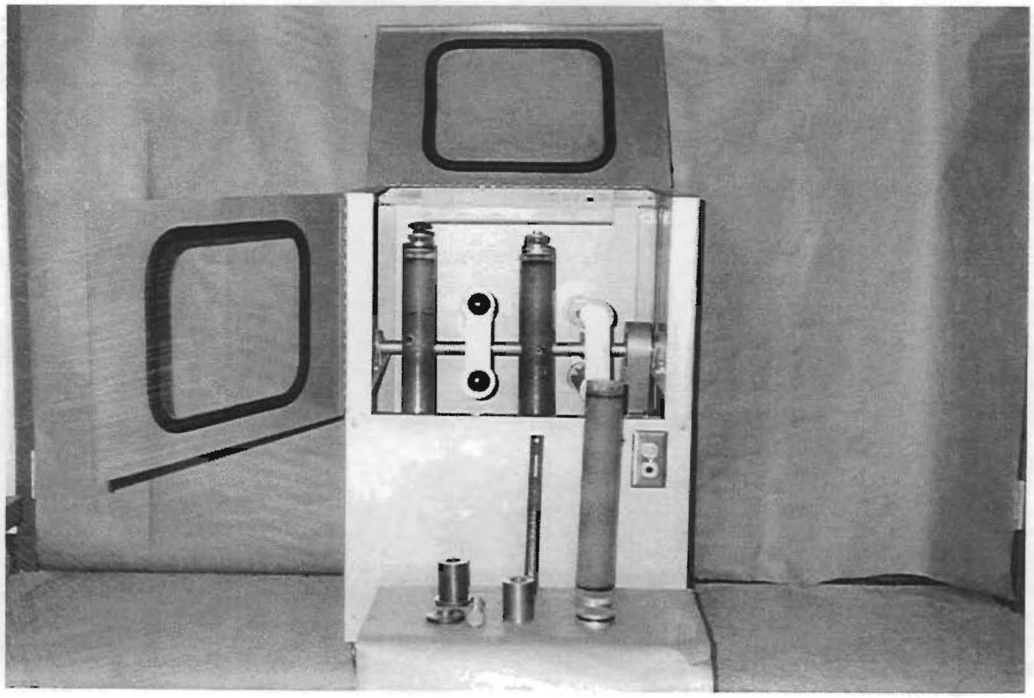

Figure 4. Schulze-Breuer test device

8. A metal pan, of at least 203 mm (8 in) diameter and 4 mm (0.16 in) copper wires for freely suspending open top 50 mm diameter x 50 mm (2 in x 2 in) high 'chicken' wire baskets.

Sample Preparation and Testing Procedure

The materials were thoroughly pre-mixed before adding the emulsified asphalt. The emulsion was mixed until it broke. Because five samples were required, 300 grams of aggregate passing the 2.00 mm (No. 10) sieve were used with the appropriate amounts of cement, water, and emulsion as stipulated by the formulations. The mixture was air cured for at least one hour, and then dried to a constant weight in a 60°C (140°F) forced draft oven. The pill molds were preheated to 60°C (140°F). Forty grams of the dried, uniformly crumbed mixture were placed in the mold, and immediately pressed using a 1000 kg (2204 lb) load for one minute. All loose edges were trimmed flush and the pieces were removed. The resulting pill was weighed to the nearest 0.01 gram. This weight should be within one gram of forty grams. The pill was then soaked in distilled water at 25°C (77°F) for six days. After the six day soaking period, the sample was surface dried and weighed. The gain in weight was recorded as absorption. The test cylinders were filled with 750 ml (25.4 oz) of ambient temperature distilled water. The pills were placed into the water filled shuttles, one per shuttle. The shuttles were then closed and tumbled in the abrasion machine for three hours. After three hours, the pill was once more surface dried and weighed to the nearest 0.01 gram to determine the abrasion loss. To test the "Integrity" of the sample, which is the Ruck procedure, it was vigorously boiled in water for 30 minutes while suspended in a wire basket. The saturated surface dry (SSD) weight of the largest remaining coherent mass of the sample was expressed as the percentage of the original mass. After air drying the sample for 24 hours, a subjective estimate was made of the aggregate filler particles that are completely coated with bitumen. The relative percentage was recorded as the adhesion.

CHAPTER 3
REPEATABILITY OF ISSA TESTS AND FORMULATION OF PRECISION STATEMENTS

GENERAL

In this chapter, the repeatability of test results obtained from the four mixture design tests proposed by the ISSA are examined. The tests examined include:

- ISSA No. 139 : Method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics;
- ISSA No. 100 : Method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak;
- ISSA No. 109 : Method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion; and
- ISSA No. 144 : Method for the classification of aggregate filler-bitumen compatibility by Schulze-Breuer and Ruck procedures.

Asphalt emulsion content was the only variable for any specific combination of aggregate and emulsion. Water content and mineral filler amounts were kept constant for all tests.

MATERIALS

All the materials used in sample preparation represent typical materials utilized for micro-surfacing projects in Texas. The emulsion type used in all cases is CSS-1hP. The aggregates used in the study satisfy Grade II requirements for coarse graded surface course as given in the TxDOT draft Micro-Surfacing Procedure, and Type II of the ISSA design bulletin recommended performance guidelines for micro-surfacing (Jan. 1991) (5).

The aggregate was thoroughly dried in 60°C (140°F) rooms for periods not less than forty-eight hours to control moisture in the samples. Distilled water was used for the preparation of all samples. Lump free portland cement was used as mineral filler for all samples. No set retarding chemicals (additive) were included for sample preparation in this study. Table 1 shows the materials used and the suppliers.

Table 1. Description of materials and material suppliers

MATERIAL	MATERIAL SUPPLIER
Grade II coarse graded surface aggregate	Delta Materials Marble Falls, Texas
Grade II coarse graded surface aggregate	TransPecos Materials Vehalen, Texas
Asphalt emulsion CSS-1hP	Ergon Asphalt and Emulsion East Waco, Texas
Asphalt emulsion CSS-1hP	Koch Material Company Salina, Kansas

ESTIMATING THE AMOUNT OF VARIABILITY PER TEST

Experience with highway materials indicates that tests performed on presumably identical materials under tightly controlled circumstances rarely yield the same results. This can be attributed to unavoidable random errors inherent in every sampling and testing procedure (6). All factors that affect the results of a test cannot be entirely controlled. Therefore, in making practical judgements and in interpreting the test data, the inherent variability has to be taken into account. For instance, the difference between a test result and some specified value may be within that which can be expected due to unavoidable random errors, in which case, a real deviation from the specified value has not been demonstrated. Similarly, the difference between two test results from two batches of materials will not indicate a fundamental quality difference if the difference is no more than can be attributed to inherent variability in the test procedure.

There are many contributing factors to the variability observed in the application of a test procedure. These factors may include operator induced errors, equipment based errors, the method of calibration, and the environment present at the time of testing (6).

Precision in test methods is expressed in terms of two measurement concepts: repeatability and reproducibility (6). Under repeatability conditions, the factors responsible for variability within test results mentioned hitherto are kept reasonably constant and usually contribute minimally to the variability of test results.

The objective underlying this rigorous statistical treatment was to determine if adequately consistent data can be generated from the various tests. Precision statistics were generated to formulate a precision statement.

Statistical Analysis

The statistical analysis of the data to estimate precision was a one-way analysis of variance performed separately for each material property level. This implies that varying amounts of the same material mixed together were considered different materials in these tests. Essentially, this exercise examined variability trends, which were expected to be reasonably consistent for differing materials mixed in accordance with a common formulation. (7)

The test method includes four classes of materials. Table 2 lists all the different material combinations (p) of emulsion brand and aggregate source investigated. Table 3 shows the number of test replicates per cell (n). Three different property test levels are used. The first property level termed Formulation "A" has a low emulsion content of ten percent asphalt emulsion. Formulation "B" has a medium emulsion content of twelve percent, and Formulation "C" has a high emulsion content of fourteen percent. All the formulations used 0.75 percent portland cement as mineral filler. Twelve percent water was used to mix all formulations, and no additive was used. The analysis was carried out for all four main ISSA design tests.

Calculation of Statistics

Cell Average x

The cell average for each material is calculated using:

$$\bar{X} = \sum_{1}^{n}\left(\frac{x}{n}\right) \tag{1}$$

where:

$\bar{X}$ = the average of the test results in one cell

x = the individual test results in one cell

n = the number of test results in one cell

Thus, in Table 4, which shows the averages for the 24-hour cured cohesion test, the average for formulation A and material 1dk are derived as shown below

$$\bar{X} = \frac{(22 + 22.5 + 22.5 + 23 + 21)}{5} = 22.2$$

Table 2. Combination of different emulsion brands and aggregate sources

No.	Abbreviation	Material Combination
1	dk	Delta aggregate and Koch emulsion
2	de	Delta aggregate and Ergon emulsion
3	tk	TransPecos aggregate and Koch emulsion
4	te	TransPecos aggregate and Ergon emulsion

Table 3. Experimental design format for investigating variability in test results

AC Content		Low		Optimum		High	
Test	Emulsion / Aggregate	Koch	Ergon	Koch	Ergon	Koch	Ergon
Cohesion	Delta	5	5	5	5	5	5
	TransPecos	5	5	5	5	5	5
Wet Track	Delta	5	5	5	5	5	5
	TransPecos	5	5	5	5	5	5
Loaded Wheel	Delta	5	5	5	5	5	5
	TransPecos	5	5	5	5	5	5
Schulze-Breuer	Delta	5	5	5	5	5	5
	TransPecos	5	5	5	5	5	5

Low AC content is 10 percent emulsion.
Optimum AC content is 12 percent emulsion.
High AC content is 14 percent emulsion.

Cell Standard Deviation

The cell standard deviation, s, of the test results in each cell is calculated using the following equation:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x - \bar{X})^2}{(n - 1)}} \qquad (2)$$

where:

$\bar{X}$ = the average of the test results in one cell

x = the individual test results in one cell
n = the number of test results in one cell

The same methods for calculating mean and standard deviation were used to generate Tables 5 through 11. In addition the range (Range) of test values (lowest and highest) are given. The mean value, plus and minus two times the standard deviation (d2s) are also provided in these tables. This information gives an indication of the overall variability. The raw data generated by each of five tests in each cell are given in Appendix A.

To illustrate the calculation of the precision statistics, the material combination of Delta aggregate and Koch emulsion (1dk) with Formulation A of Table 12 were used in a study work sheet as an example to illustrate the generation of all the tabulated statistics. Table 12 is the statistical analysis on 24-hour cured cohesion test results. From the Formulation A study work sheet, the cell standard deviation of the test results for material combination 1dk is:

$$s = \sqrt{\frac{(22.0-22.2)^2+(22.5-22.2)^2+(22.5-22.2)^2+(23-22.2)^2+(21.0-22.2)^2}{4}} = 0.8$$

Table 4. Results of 24-hour cured cohesion test data

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	21.0-23.0	22.2	0.8	20.6-23.8	20.0-22.5	21.4	1.0	19.4-23.4	20.0-22.5	21.4	1.0	19.4-23.4
2	de	19.5-20.5	20.0	0.4	19.2-20.8	16.5-20.0	18.4	1.4	15.6-21.2	21.0-22.0	21.6	0.4	20.8-22.4
3	tk	18.5-21.0	19.8	1.0	17.8-21.8	19.5-23.0	21.0	1.3	18.4-23.6	22.0-25.0	23.1	1.1	20.9-25.3
4	te	22.5-26.0	24.5	1.3	21.9-27.1	21.0-24.0	22.8	1.3	20.2-25.4	16.5-21.0	19.0	0.6	17.8-20.2

Table 5. Results of 30-minute modified cohesion test data

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	8.0-10.0	12.7	0.5	11.7-13.7	7.0-11.0	8.0	1.7	4.6-11.4	16.0-17.0	14.7	0.4	13.9-15.5
2	de	12.0-13.0	12.7	0.4	11.9-13.5	17.0-21.0	18.7	1.7	15.3-22.1	15.0-19.5	17.5	1.8	13.9-21.1
3	tk	8.0-10.0	8.9	0.7	7.5-10.3	6.0-9.0	7.4	1.2	5.0-9.8	6.0-6.5	6.2	0.3	5.6-6.8
4	te	14.0-17.0	15.5	1.1	13.3-17.7	15.0-22.0	19.1	2.5	14.1-24.1	14.0-14.5	14.2	1.0	12.2-16.2

Table 6. Results of 60-minute modified cohesion test data

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	9.0-10.5	9.9	0.7	8.5-11.3	6.5-9.0	8.1	1.0	6.1-10.1	7.5-8.5	8.0	0.4	7.2-8.8
2	de	12.0-14.0	12.9	0.7	11.5-14.3	14.0-20.0	16.7	2.5	11.7-21.7	15.5-21.0	18.6	2.3	14.0-23.2
3	tk	9.5-11.0	10.1	0.7	8.7-11.5	9.5-11.0	10.2	0.6	9.0-11.4	7.5-9.0	8.3	0.7	6.9-9.7
4	te	16.5-18.0	17.1	0.6	15.9-18.3	18.5-24.0	20.7	2.0	16.7-24.7	14.0-17.5	15.8	1.6	12.6-19.0

Table 7. Results of wet track abrasion (1-hour soak) test data

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	13.2-113.4	55.0	38.0	0-131.0	61.7-91.9	77.1	11.3	54.5-99.7	38.6-56.2	44.3	7.2	29.9-58.7
2	de	36.8-167.3	80.6	51.9	0-184.4	9.8-43.4	22.6	12.5	0-47.6	6.3-33.6	22.8	11.0	0.8-44.8
3	tk	22.8-46.5	34.6	11.7	11.2-58.0	5.3-13.0	8.1	3.2	1.7-14.5	17.4-30.5	23.4	6.7	10.0-36.8
4	te	19.0-45.9	29.5	12.6	4.3-54.7	37.5-45.9	41.0	3.5	34.0-48.0	0.4-6.2	4.0	2.3	0-8.6

Table 8. Results of wet track abrasion (6-day soak) test data

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	24.8-36.6	28.9	5.2	18.5-39.3	160.2-320.3	239.4	58.6	122.2-356.6	67.1-100.8	83.2	13.4	56.4-110.0
2	de	8.9-96.2	35.8	34.8	0-105.4	58.6-109.5	78.9	18.7	41.9-116.3	19.2-70.8	48.0	22.0	6.0-92.0
3	tk	34.0-68.6	47.9	13.8	20.3-75.5	57.4-85.9	73.4	11.5	50.4-96.4	49.5-234.4	110.3	72.1	0-254.5
4	te	40.1-153.6	90.8	41.9	7.0-174.6	40.5-138.9	92.1	45.6	0.9-183.3	12.7-45.3	35.4	13.4	8.6-62.2

Table 9. Results of loaded wheel test data

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	55.6-60.7	58.2	2.4	53.4-63.0	72.5-92.4	81.2	7.2	66.8-95.6	90.2-118.0	105.8	10.6	84.6-127.0
2	de	56.0-82.7	75.4	11.1	53.2-97.6	64.1-91.1	77.2	11.6	54.5-100.9	78.1-131.7	102.5	22.2	58.1-146.9
3	tk	43.0-64.7	54.1	9.4	35.3-72.9	46.5-86.7	62.6	16.8	29.0-96.2	55.6-60.7	58.2	2.4	53.4-63.0
4	te	60.4-73.4	67.3	6.3	54.7-92.5	45.0-129.0	75.9	33.1	9.7-142.1	53.4-97.8	79.0	20.4	38.2-119.8

Table 10. Results of abrasion (Schulze-Breuer and Ruck procedures)

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	1.5-3.9	3.1	0.94	1.22-4.98	2.5-2.9	2.7	0.20	2.1-3.1	0.8-1.5	1.1	0.25	0.60-1.60
2	de	1.1-1.7	1.4	0.20	1.00-1.80	0.7-2.0	1.4	0.47	0.46-2.34	1.0-2.2	1.3	0.56	0.48-2.42
3	tk	0.7-1.1	0.9	0.18	0.54-1.26	2.6-5.6	4.2	1.21	1.78-6.62	1.6-2.7	1.9	0.46	0.98-2.82
4	te	1.5-2.1	1.8	0.24	1.32-2.28	0.6-0.8	0.8	0.10	0.60-1.00	0.1-0.4	0.3	0.12	0.06-0.54

Table 11. Results of integrity (Schulze-Breuer and Ruck procedures)

No.	Mat'l	Formulation A				Formulation B				Formulation C			
		Range	Mean	Std. Dev	d2s	Range	Mean	Std. Dev.	d2s	Range	Mean	Std. Dev.	d2s
1	dk	0.0-0.0	0.0	0.0	0.0-0.0	0.0-88.1	48.4	44.5	0-137.4	0.0-93.8	52.0	47.7	0-147.4
2	de	93.1-96.6	94.1	1.5	91.1-97.1	98.1-99.2	98.6	0.5	97.6-99.6	95.4-99.8	97.2	1.9	93.4-101.0
3	tk	82.3-90.7	87.3	3.3	80.7-93.9	0.0-0.0	0.0	0.0	0.0-0.0	0.0-102.1	38.5	52.9	0-144.3
4	te	72.2-97.2	91.3	10.7	69.9-112.7	96.6-99.6	97.7	1.2	95.3-100.1	99.4-99.8	99.6	0.2	99.2-100.0

Table 12. Statistical analysis on 24-hour cured cohesion test result data

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	22.2	0.8	0.575	0.144	0.850
2de	20	0.4	-1.625	-0.408	0.425
3tk	19.8	1	-1.825	-0.458	1.063
4te	24.5	1.32	2.875	0.722	1.403

Average of cell averages	Ψ	21.625
Standard deviation of cell averages	Sx	3.984
Repeatability standard deviation	Sr	0.941
Reproducibility standard deviation	SR	4.072

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	21.4	1	0.5	0.173	0.794
2de	18.4	1.4	-2.5	-0.866	1.112
3tk	21	1.3	0.1	0.035	1.033
4te	22.8	1.3	1.9	0.658	1.033

Average of cell averages	Ψ	20.900
Standard deviation of cell averages	Sx	2.887
Repeatability standard deviation	Sr	1.259
Reproducibility standard deviation	SR	3.099

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	21.4	1	0.05	0.021	1.210
2de	21.6	0.4	0.25	0.106	0.484
3tk	23.1	1.1	1.75	0.739	1.332
4te	19.0	0.6	-2.05	-0.866	0.726

Average of cell averages	Ψ	21.350
Standard deviation of cell averages	Sx	2.367
Repeatability standard deviation	Sr	0.826
Reproducibility standard deviation	SR	2.480

Intermediate Statistics

The principal variant in the precision conditions under investigation is the formulation used for each material combination. The usual factors that determine precision condition, such as different operator technique bias, the calibration of different pieces of the same equipment, and the variation of environmental conditions (6) were assumed to be non-existent. This assumption was made because the tests were all conducted by one operator, using the same piece of equipment per specific test, within a single laboratory.

Average of Cell Averages

The average of cell averages, Ψ, measures the closeness of agreement between the test results obtained under specified intermediate precision conditions. The average is more characteristic of the formulation used than of the test method. This is because all test samples are obtained from material quantities that were very homogenous by comparison to field samples. An assumption of homogeneity can be made because all materials meet the TxDOT micro-surfacing material specifications.

$$\Psi = \sum_{i=1}^{n} \overline{X}/p \qquad (3)$$

where:

Ψ = the average of the cell averages for a particular formulation

$\overline{X}$ = the individual cell averages and

p = the number of material combinations

n = the number of test results in one cell

Thus, for Formulation A in Table 12

$$\Psi = (22.2 + 20 + 19.8 + 24.5) / 4 = 21.625$$

Cell Deviation

Cell deviation, d, is a sensitive measurement for comparing the variability of two sets of measurements, but also for interpreting the variability of a set of measurements (8). For each material combination level, the cell deviation, d, is calculated by subtracting the cell average, ., from the average of the cell averages, Ψ, using the following equation:

$$d = \overline{X} - \Psi \tag{4}$$

where:

. = the individual cell averages
Ψ = average of the cell averages

Thus, for material combination 1dk with Formulation A in Table 12,

$$d = 22.2 - 21.625 = 0.575$$

Standard Deviation of the Cell Averages

Standard deviation of the cell averages, Sx, is the statistical measure of the dispersion of observed results expressed as the positive square root of the variance (6). This statistic is calculated using the following equation:

$$Sx = \sqrt{\sum_{i=1}^{p} (d_i^2 \ / \ [p-1])} \tag{5}$$

where:

d = cell average x from the average of the cell averages, Ψ
p = the number of material combinations

Therefore, Sx for Formulation A in Table 12 can be calculated as follows,

$$Sx = \sqrt{[(0.575)^2 + (-1.625)^2 + (-1.825)^2 + (2.875)^2] \ / \ (4-1)} = 3.984$$

Precision Statistics

The closeness of agreement between test results obtained under prescribed conditions was examined through the use of precision statistics. The prescribed conditions or repeatability conditions are the conditions under which test results are obtained with the same test method in the same laboratory by the same operator with the same equipment in the shortest practical period of time using test samples obtained at random from a single quantity of material that is as near homogenous as possible (6).

The Repeatability Standard Deviation

The repeatability standard deviation, Sr, is a fundamental precision statistic. It is the standard deviation of test results obtained under repeatability conditions. Normally, it is considered a property of the test method and is calculated as follows:

$$Sr = \sqrt{\sum_{i=1}^{p} s^2/p} \tag{6}$$

where:

Sr = the repeatability standard deviation
s = cell standard deviation (p of them from equation 2)
p = the number of different combinations of material

Hence, Sr for Formulation A in Table 12

$$Sr = \sqrt{[(0.8)^2 + (0.4)^2 + (1)^2 + (1.32)^2] / 4} = 0.946$$

If the test procedure is repeatable, although the mean values would be different, the standard deviations should be about the some. If this is true, the Sr will equal the individual standard deviations, and errors will be due to the tests, not the material difference.

The Reproducibility Standard Deviation

The reproducibility standard deviation, SR, is the standard deviation of test results obtained under reproducibility conditions. These are conditions under which test results are obtained with the same test method on identical formulations using different material combinations (6). This is calculated using the following equation

$$SR = \sqrt{(Sx)^2+(Sr)^2(n-1)/n} \tag{7}$$

where, Sx and Sr are obtained from equations 5 and 6.

Thus, for Formulation A in Table 12:

$$SR=\sqrt{(3.984)^2+(0.941)^2(5-1)/5} = 4.072$$

Consistency Statistics h and k

For each cell, a value of h using the following equation was calculated (6):

$$h = d/S_x \tag{8}$$

where:

h is defined as the between material combination consistency statistic

d = the cell deviation i.e, the deviation of the cell average from the average of the cell averages

Sx = the standard deviation of the cell averages

Thus, for material combination 1dk with Formulation A in Table 12:

$$h = 0.575/3.984 = 0.173$$

If h is low, the variability will be primarily due to test variability. If it is high, material combinations have an effect on variability.

For each cell, the following equation can be used to calculate a value of k

$$k = s/Sr \tag{9}$$

where:

k is defined as the material formulation consistency statistic (6)

s = the cell standard deviation for one material

Sr = the repeatability standard deviation of the material

Thus, for material combination 1dk with Formulation A in Table 12:

$$k = 0.8/0.941 = 0.850$$

The values of k determine if one material combination has high variability compared to others.

Tables 12 - 19 contain the precision statistics for all the tests and were generated in the manner described above.

Critical Values of h and k Statistic

Critical values of the h and k consistency statistics are chosen at the 0.5 percent significance level. The 0.5 percent level was chosen based on the fact that 1.0 percent normally results in too many cells being unacceptable and the 0.1 percent level in too few cells being unacceptable (6). The critical value for h depends on the number of different combinations of emulsion brand and aggregate source to form what is termed as a material combination or type (p) and on the number of replicate test results (n) per test on specific quantities of material type.

Table 13. Statistical analysis on 30-minute modified cohesion test data

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	12.7	0.5	0.25	0.061	0.597
2de	12.7	0.4	0.25	0.061	1.075
3tk	8.9	0.7	-3.55	-0.866	0.836
4te	15.5	1.12	3.05	0.744	1.338

Average of cell averages	Ψ	12.450
Standard deviation of cell averages	Sx	4.099
Repeatability standard deviation	Sr	0.837
Reproducibility standard deviation	SR	4.167

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	8	1.7	-5.3	-0.410	0.926
2de	18.7	1.7	5.4	0.418	0.926
3tk	7.4	1.2	-5.9	-0.456	0.654
4te	19.1	2.5	5.8	0.448	1.362

Average of cell averages	Ψ	13.300
Standard deviation of cell averages	Sx	12.933
Repeatability standard deviation	Sr	1.835
Reproducibility standard deviation	SR	13.036

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	14.7	0.4	-1.05	-0.379	0.565
2de	17.5	1.8	1.95	0.704	1.563
3tk	6.2	0.3	0.45	0.162	0.695
4te	14.2	1	-1.35	-0.487	0.869

Average of cell averages	Ψ	15.550
Standard deviation of cell averages	Sx	2.771
Repeatability standard deviation	Sr	1.151
Reproducibility standard deviation	SR	2.956

Table 14. Statistical analysis on 60-minute modified cohesion test data

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	9.9	0.7	-2.6	-0.450	1.018
2de	12.9	0.7	0.4	0.069	1.018
3tk	10.1	0.7	-2.4	-0.416	1.018
4te	17.1	0.65	4.6	0.797	0.945

Average of cell averages	Ψ	12.500
Standard deviation of cell averages	Sx	5.774
Repeatability standard deviation	Sr	0.688
Reproducibility standard deviation	SR	5.806

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	8.1	1	-5.825	-0.528	0.587
2de	16.7	2.5	2.775	0.252	1.467
3tk	10.2	0.6	-3.725	-0.338	0.352
4te	20.7	2	6.775	0.614	1.174

Average of cell averages	Ψ	13.925
Standard deviation of cell averages	Sx	11.027
Repeatability standard deviation	Sr	1.704
Reproducibility standard deviation	SR	11.132

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	8	0.4	-4.675	-0.447	0.274
2de	18.6	2.3	5.925	0.567	1.578
3tk	8.3	0.7	-4.375	-0.419	0.480
4te	15.8	1.6	3.125	0.299	1.098

Average of cell averages	Ψ	12.675
Standard deviation of cell averages	Sx	10.450
Repeatability standard deviation	Sr	1.458
Reproducibility standard deviation	SR	10.531

Table 15. Statistical analysis on wet track abrasion (1-hour soak) test data

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	55.00	37.95	5.0675	0.123	1.140
2de	80.63	51.9	30.6975	0.743	1.560
3tk	34.64	11.74	-15.2925	-0.370	0.353
4te	29.46	12.55	-20.4725	-0.496	0.377

Average of cell averages	Ψ	49.933
Standard deviation of cell averages	Sx	41.298
Repeatability standard deviation	Sr	33.276
Reproducibility standard deviation	SR	50.905

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	77.08	11.26	42.2225	0.808	1.212
2de	22.61	12.5	-15.3375	-0.294	1.488
3tk	8.05	3.15	-29.8975	-0.572	0.375
4te	40.96	3.52	3.0125	0.058	0.419

Average of cell averages	Ψ	37.948
Standard deviation of cell averages	Sx	52.233
Repeatability standard deviation	Sr	8.399
Reproducibility standard deviation	SR	52.770

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	44.27	7.18	3.7875	0.058	1.056
2de	22.78	11	-17.7025	-0.269	1.617
3tk	23.38	6.68	-39.2225	-0.597	0.053
4te	3.97	2.31	53.1375	0.808	0.517

Average of cell averages	Ψ	40.483
Standard deviation of cell averages	Sx	65.731
Repeatability standard deviation	Sr	6.802
Reproducibility standard deviation	SR	66.012

Table 16. Statistical analysis on wet track abrasion (6-day soak) test result data

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	28.9	5.22	-21.96	-0.476	0.185
2de	35.82	34.79	-15.04	-0.326	1.233
3tk	47.91	13.81	-2.95	-0.064	0.490
4te	90.81	41.88	39.95	0.866	1.485

Average of cell averages	Ψ	50.860
Standard deviation of cell averages	Sx	46.130
Repeatability standard deviation	Sr	28.206
Reproducibility standard deviation	SR	52.578

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	239.38	58.65	118.46	0.866	1.514
2de	78.85	18.7	-42.07	-0.308	0.483
3tk	73.39	11.46	-47.53	-0.347	0.296
4te	92.06	45.59	-28.86	-0.211	1.177

Average of cell averages	Ψ	120.920
Standard deviation of cell averages	Sx	136.786
Repeatability standard deviation	Sr	38.728
Reproducibility standard deviation	SR	141.104

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	83.2	13.45	40.815	0.761	1.031
2de	48.04	22.02	5.655	0.105	1.688
3tk	110.26	72.08	-36.465	-0.680	0.028
4te	35.43	13.37	-10.005	-0.186	0.297

Average of cell averages	Ψ	42.385
Standard deviation of cell averages	Sx	53.659
Repeatability standard deviation	Sr	13.047
Reproducibility standard deviation	SR	54.913

Table 17. Statistical analysis on loaded wheel test result data

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	58.15	2.36	-5.585	-0.318	0.294
2de	75.43	11.14	11.695	0.665	1.387
3tk	54.09	9.43	-9.645	-0.548	1.174
4te	67.27	6.28	3.535	0.201	0.782

Average of cell averages	Ψ	63.735
Standard deviation of cell averages	Sx	17.586
Repeatability standard deviation	Sr	8.032
Reproducibility standard deviation	SR	18.997

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	81.23	7.25	6.975	0.514	0.504
2de	77.65	11.59	3.275	0.241	0.577
3tk	62.63	16.76	-11.745	-0.866	0.835
4te	78.99	20.39	1.495	0.110	1.648

Average of cell averages	Ψ	74.375
Standard deviation of cell averages	Sx	13.562
Repeatability standard deviation	Sr	20.083
Reproducibility standard deviation	SR	22.507

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	105.76	10.55	15.7525	0.428	0.842
2de	102.5	22.24	12.4925	0.340	1.776
3tk	58.15	2.36	-31.8575	-0.866	0.188
4te	78.99	20.39	3.6125	0.098	0.319

Average of cell averages	Ψ	90.008
Standard deviation of cell averages	Sx	36.786
Repeatability standard deviation	Sr	12.525
Reproducibility standard deviation	SR	38.454

Table 18. Statistical analysis on abrasion (Schulze-Breuer and Ruck procedures)

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	3.078	0.944	1.29575	0.866	1.869
2de	1.425	0.196	-0.35725	-0.239	0.388
3tk	0.851	0.181	-0.93125	-0.622	0.358
4te	1.775	0.242	-0.00725	-0.005	0.479

Average of cell averages	Ψ	1.782
Standard deviation of cell averages	Sx	1.496
Repeatability standard deviation	Sr	0.505
Reproducibility standard deviation	SR	1.563

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	2.706	0.199	0.443	0.160	0.303
2de	1.378	0.468	-0.885	-0.320	0.713
3tk	4.212	1.206	1.949	0.706	1.838
4te	0.756	0.099	-1.507	-0.546	0.151

Average of cell averages	Ψ	2.263
Standard deviation of cell averages	Sx	2.762
Repeatability standard deviation	Sr	0.656
Reproducibility standard deviation	SR	2.824

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	1.08	0.251	-0.06775	-0.062	0.650
2de	1.313	0.558	0.16525	0.150	1.445
3tk	1.936	0.455	0.78825	0.716	1.178
4te	0.262	0.123	-0.88575	-0.804	0.319

Average of cell averages	Ψ	1.148
Standard deviation of cell averages	Sx	1.101
Repeatability standard deviation	Sr	0.386
Reproducibility standard deviation	SR	1.154

Table 19. Statistical analysis on integrity (Schulze-Breuer and Ruck procedures)

Formulation A Study Work Sheet

Material Number	x	s	d	h	k
1dk	0	0	-68.175	-0.866	0.000
2de	94.09	1.46	25.915	0.329	0.258
3tk	87.33	3.34	19.155	0.243	0.590
4te	91.28	10.71	23.105	0.294	1.893

Average of cell averages	Ψ	68.175
Standard deviation of cell averages	Sx	78.722
Repeatability standard deviation	Sr	5.657
Reproducibility standard deviation	SR	78.884

Formulation B Study Work Sheet

Material Number	x	s	d	h	k
1dk	48.44	44.54	-12.7325	-0.149	1.999
2de	98.59	0.5	37.4175	0.438	0.022
3tk	0	0	-61.1725	-0.717	0.000
4te	97.66	1.16	36.4875	0.428	0.052

Average of cell averages	Ψ	61.173
Standard deviation of cell averages	Sx	85.338
Repeatability standard deviation	Sr	22.279
Reproducibility standard deviation	SR	87.634

Formulation C Study Work Sheet

Material Number	x	s	d	h	k
1dk	51.98	47.7	-19.8375	-0.323	1.339
2de	97.17	1.9	25.3525	0.413	0.053
3tk	38.52	52.91	-33.2975	-0.543	1.485
4te	99.6	0.18	27.7825	0.453	0.005

Average of cell averages	Ψ	71.818
Standard deviation of cell averages	Sx	61.355
Repeatability standard deviation	Sr	35.631
Reproducibility standard deviation	SR	69.138

The critical values for the h and k consistency statistics were calculated from the Student's t and the F-ratio using the following relationships:

$$h=(p-1)t\sqrt{p(t^2+p-2)}$$

where:

p = number of material combinations
t with p-2 degrees of freedom

$$k=\sqrt{(p/[1+(p-1)/F]}$$

F with n-1 and (p-1)(n-1) degrees of freedom.

Table 20 shows the critical values of h and k at the 0.5 percent significance level. Therefore, with the total number of material combinations (p) equal to 4 and the number of replicates (n) equal to five, the respective critical h and k values are 1.49 and 1.66. Actually, the critical value for h is ± 1.49, since there are both negative and positive values of h, because the numerator oscillates about the mean.

Table 20. Critical values of h and k at the 0.5 percent significance level

Critical value of h	p	Critical value of k Number of replicates, n				
		2	3	4	5	6
1.15	3	1.72	1.67	1.61	1.56	1.52
1.49	4	1.95	1.82	1.73	1.66	1.60
1.74	5	2.11	1.92	1.79	1.71	1.65
1.92	6	2.22	1.98	1.84	1.75	1.68
2.05	7	2.30	2.03	1.87	1.77	1.70
2.15	8	2.36	2.06	1.90	1.79	1.72
2.23	9	2.41	2.09	1.92	1.81	1.74
2.29	10	2.45	2.11	1.93	1.82	1.74

h-Consistency Statistic Plots

To evaluate the differences between materials, the trends exhibited by h consistency statistic plots are investigated. There are three basic trends that can be expected:

1. All the different material combinations have both positive and negative h values among the formulations,

2. The particular combination of materials have either positive or negative for all formulation and the number of negative formulations equals the number of positive formulations, more or less, and

3. One particular material combination has all the h values positive or negative, as opposed to all the other material combinations with substantially all the h values negative or (positive).

Neither of the first two patterns is unusual or requires investigation, although it may be possible to point out the nature of the test variability from it. However, if one particular combination has all the h values positive or negative, as opposed to all the other material combinations with substantially all the h values negative or positive, that calls for an immediate investigation of that material combination (6).

Figures 5 through 12 show bar graphs of the h consistency statistics grouped according to material combination along with the critical values. These figures give an instant picture of the variability of the individual test methods.

k-Consistency Statistic Plots

With the k-consistency statistic plots, the main trend for which the plots are examined is to find out if a particular material combination has large k values or very small k values for all or most of the formulations. High k values indicate imprecision within the material combination. Very small k values may indicate a very insensitive measurement scale or other measurement problem (6). Figures 13 through 20 show graphs of the k-consistency statistic grouped according to material combination.

Observations

h-Consistency Statistic

After examining Figures 5 through 10, the overall impression was that there is reasonable consistency for variation within material type combinations for each of the ISSA tests, apart from the loaded wheel test. Figure 10 (graph of the h-consistency statistic within material type combination for the loaded wheel test) shows that material combination 3 is opposed to all the other material combinations. All the other material

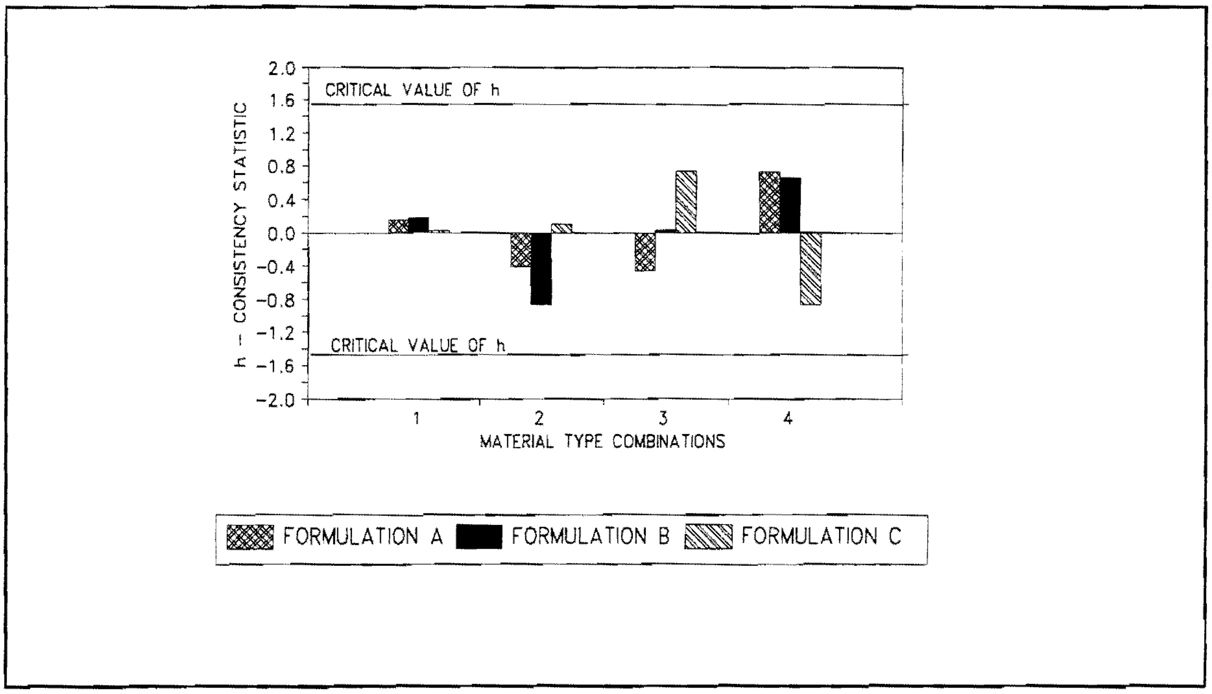

Figure 5. 24-hour cured cohesion test, plot of h-consistency statistic versus material type combinations

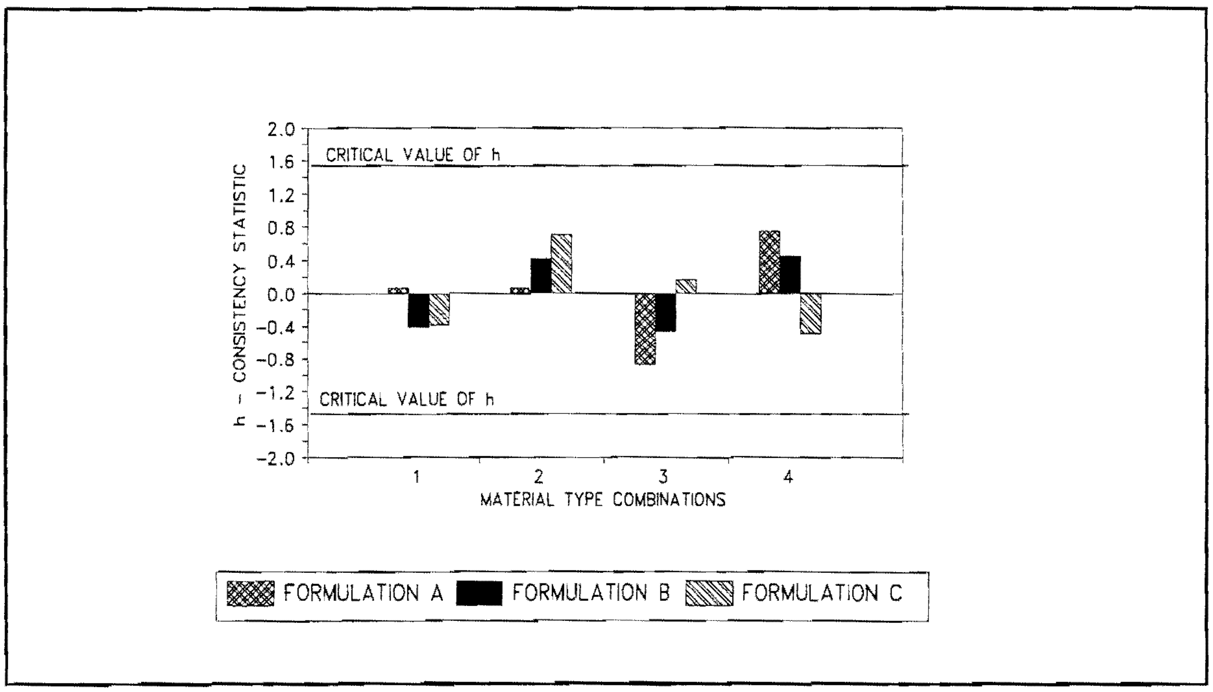

Figure 6. 30-minutes wet cohesion test, plot of h-consistency statistic versus material type combinations

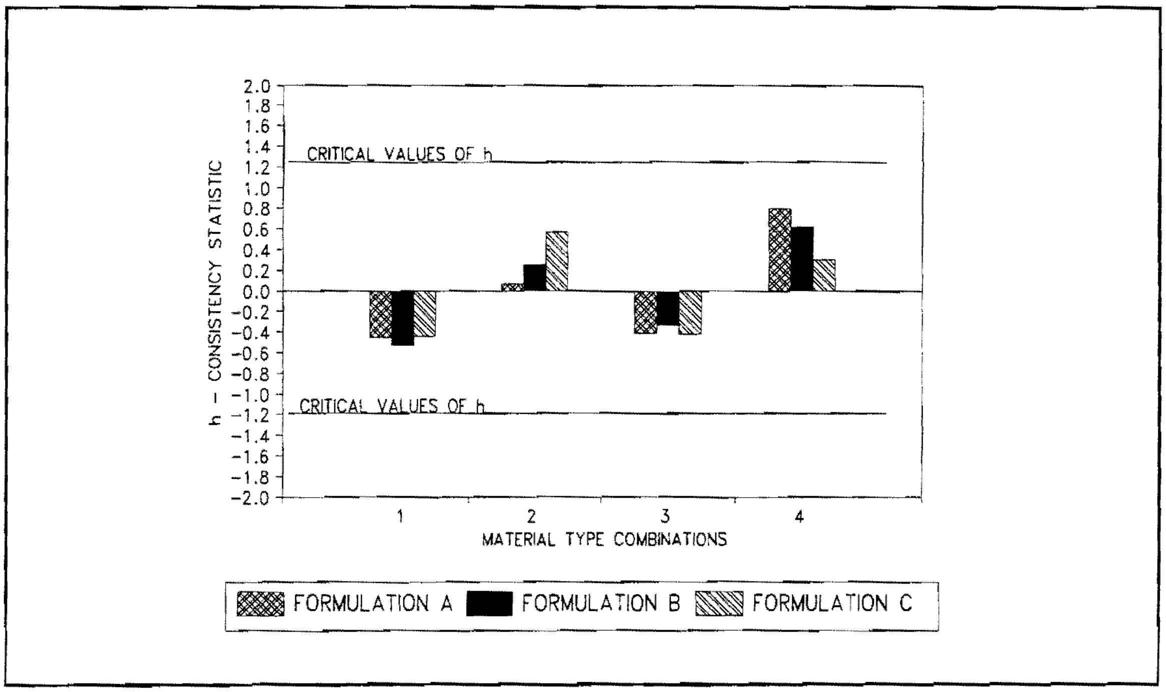

Figure 7. 60-minute wet cohesion test, plot of h-consistency statistic versus material type combinations

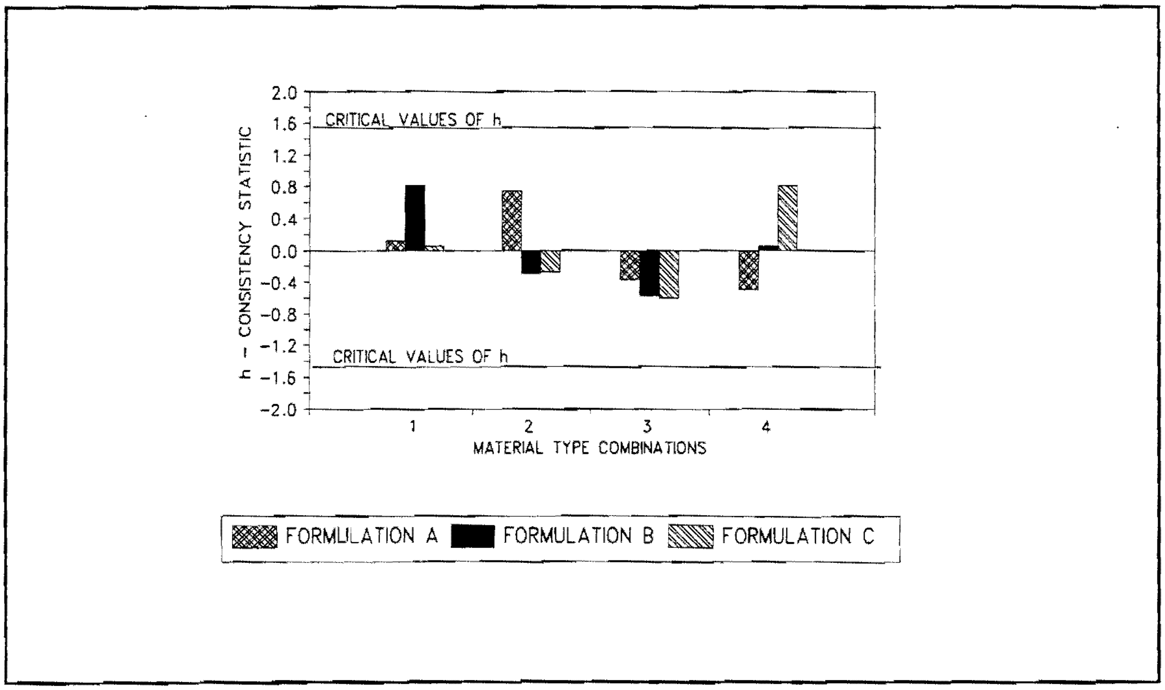

Figure 8. 1-hour soak wet track abrasion test, plot of h-consistency statistic versus material type combinations

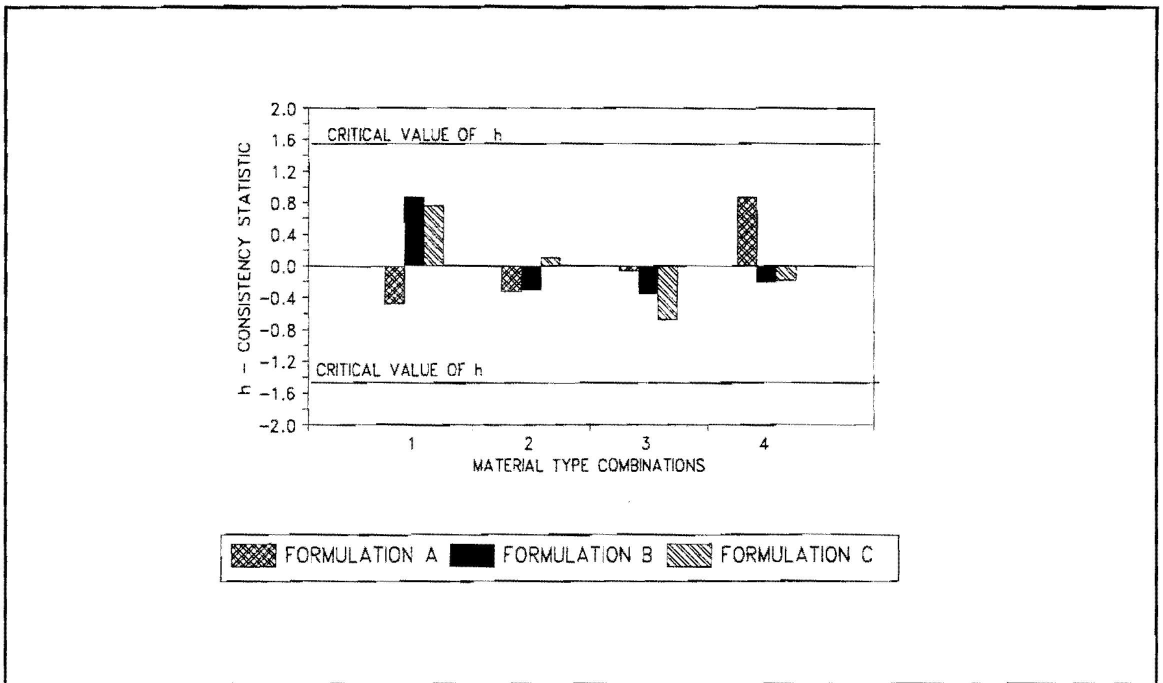

Figure 9. 6-day soak wet track abrasion test, plot of h-consistency statistic versus material type combinations

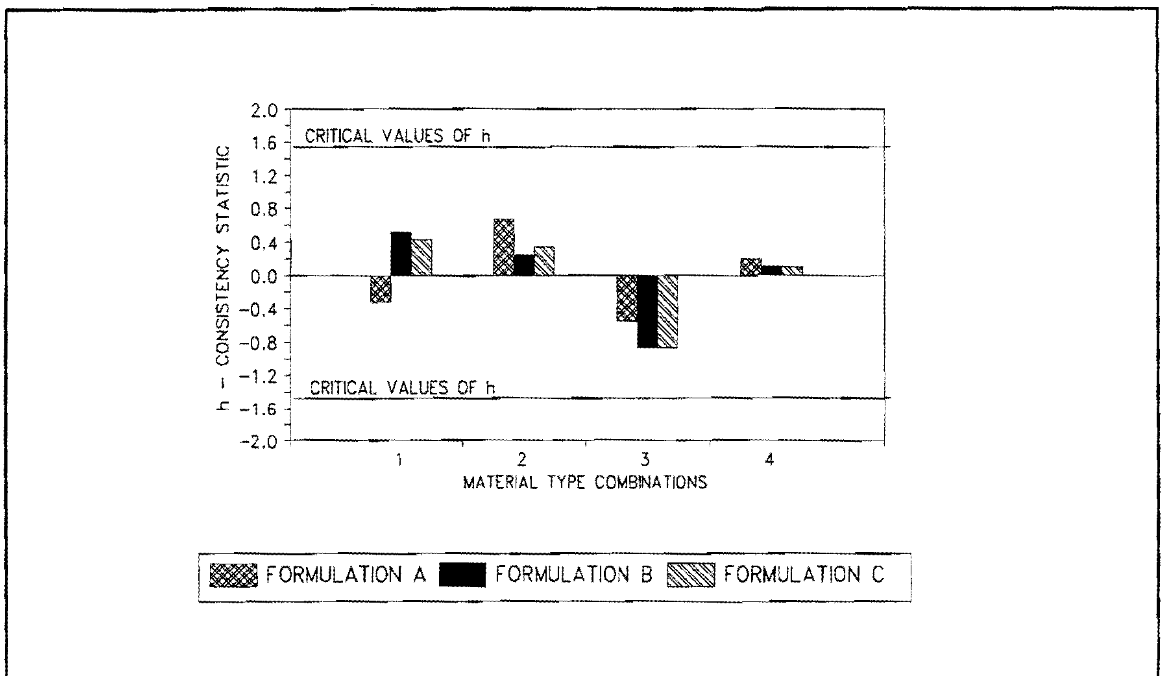

Figure 10. Loaded wheel test, plot of h-consistency statistic versus material type combinations

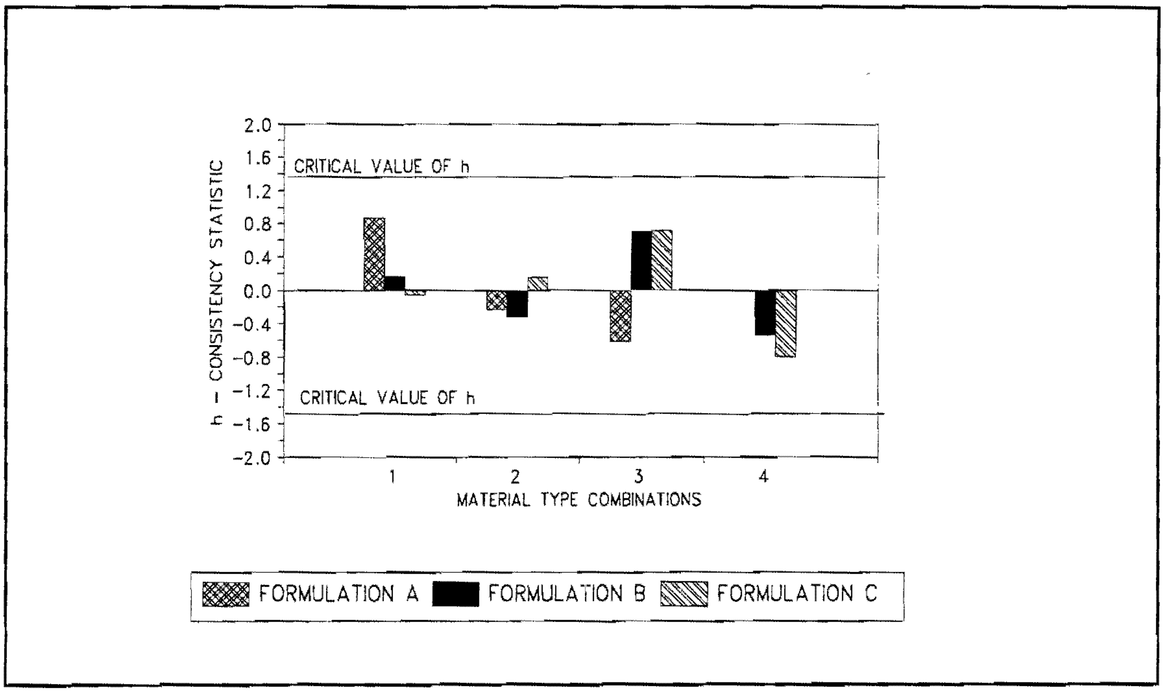

Figure 11. Schulze-Breuer and Ruck procedures (abrasion), plot of h-consistency statistic versus material type combinations

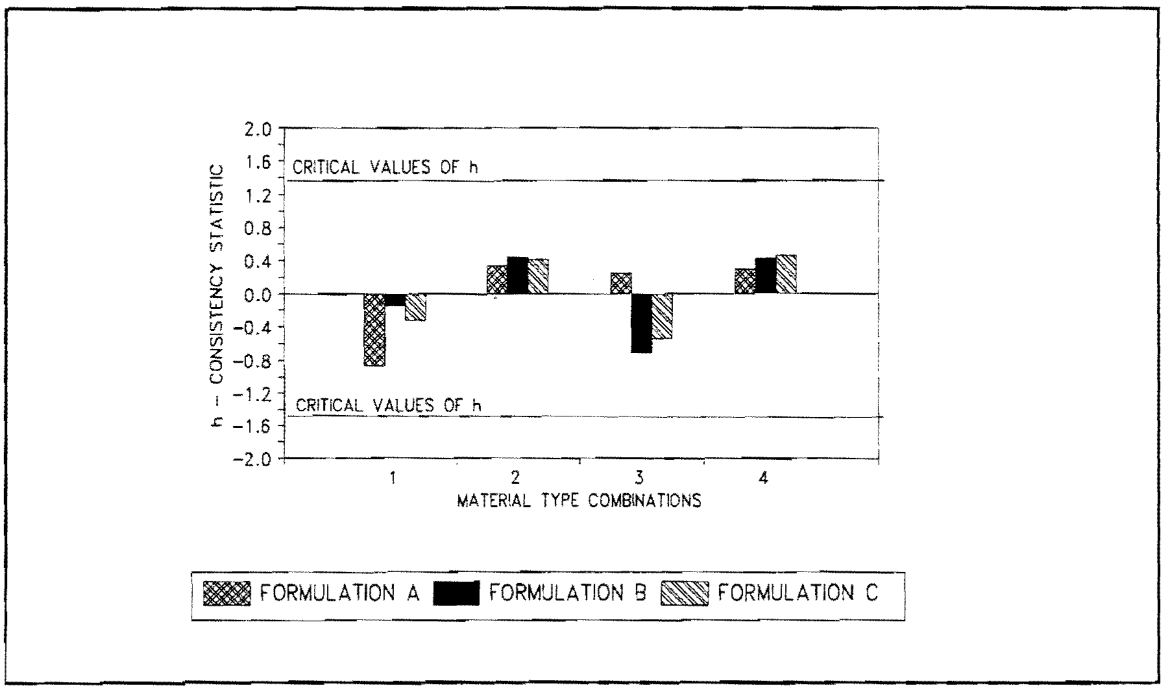

Figure 12. Schulze-Breuer and Ruck procedures (integrity), plot of h-consistency statistic versus material type combinations

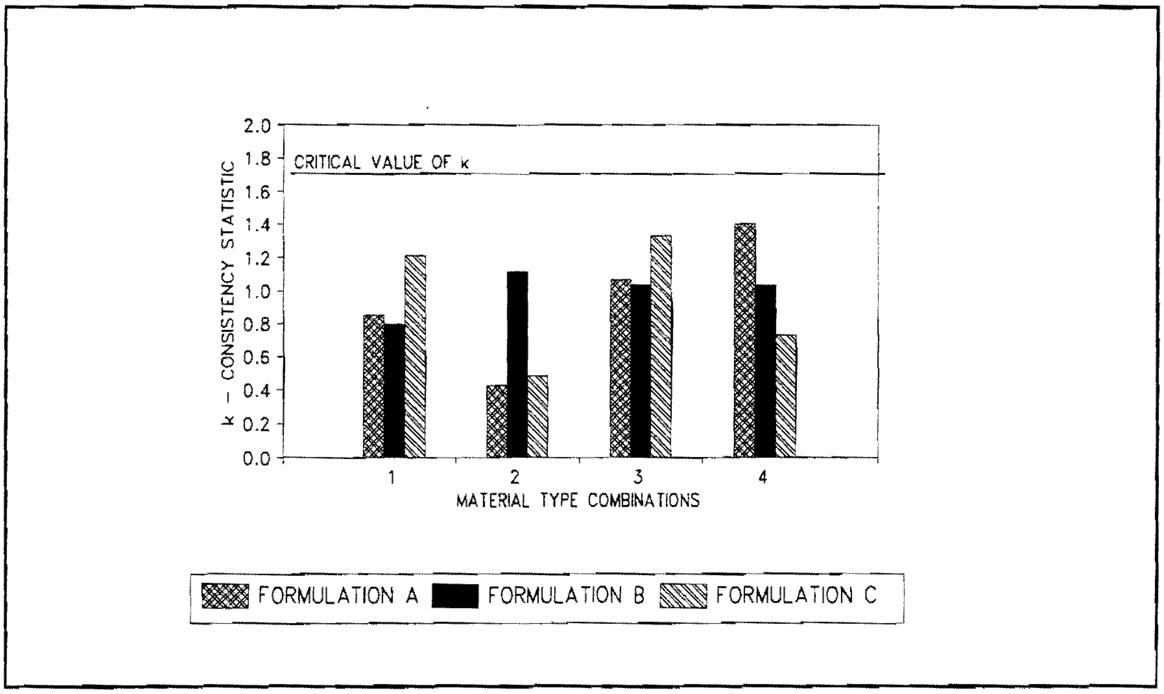

Figure 13. 24-hour cured cohesion test, plot of k-consistency statistic versus material type combinations

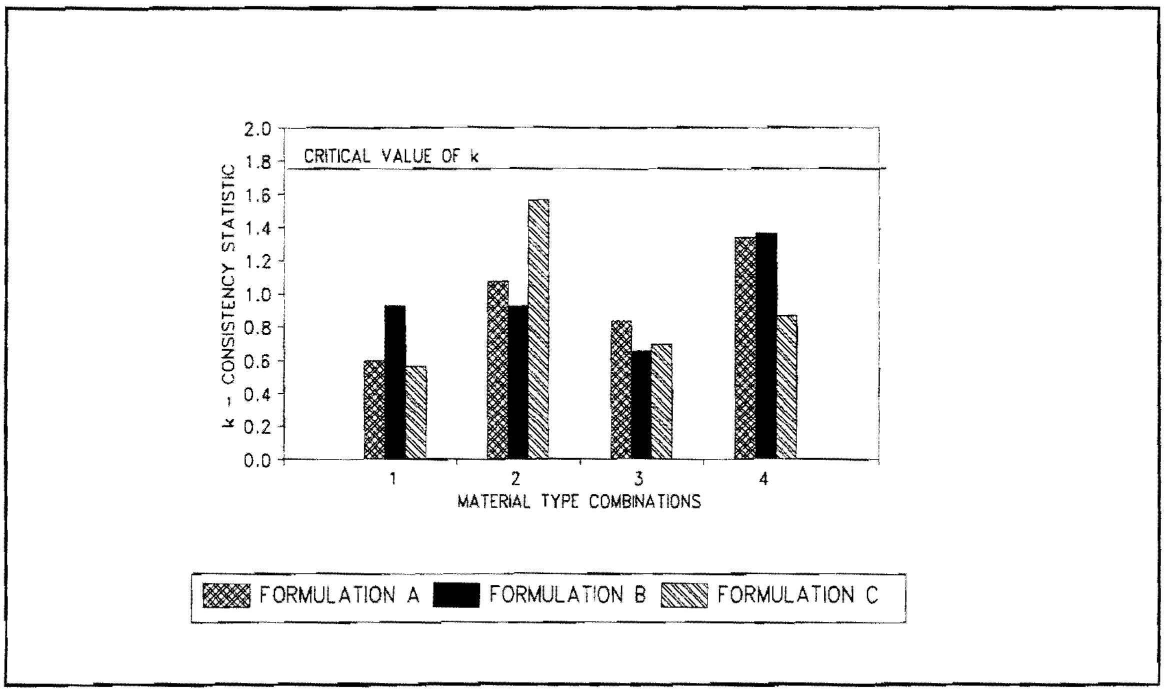

Figure 14. 30-minute wet cohesion test, plot of k-consistency statistic versus material type combinations

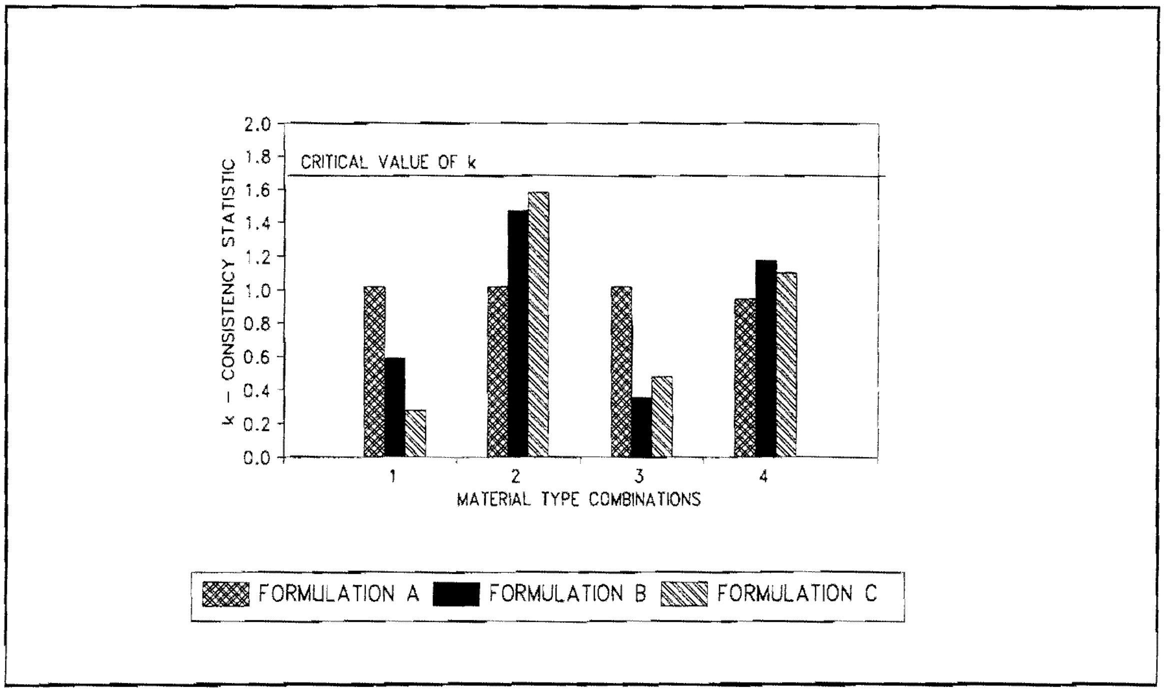

Figure 15. 60-minute wet cohesion test, plots of k-consistency statistic versus material type combinations

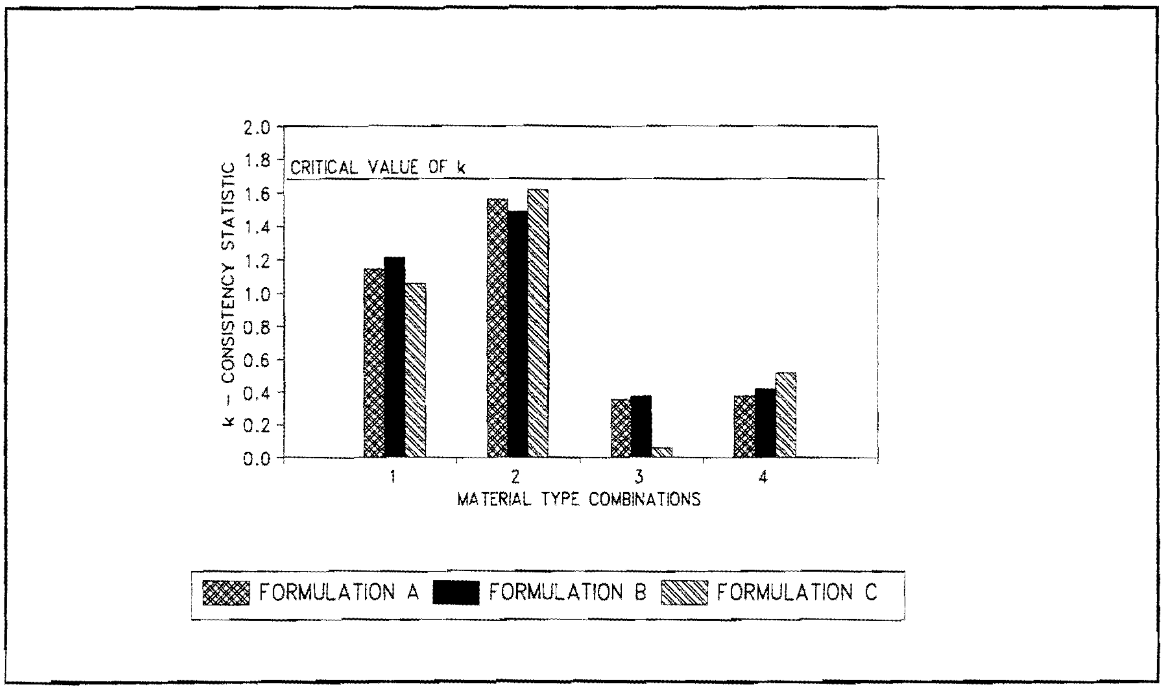

Figure 16. 1-hour soak wet track abrasion test, plot of k-consistency statistic versus material type combinations

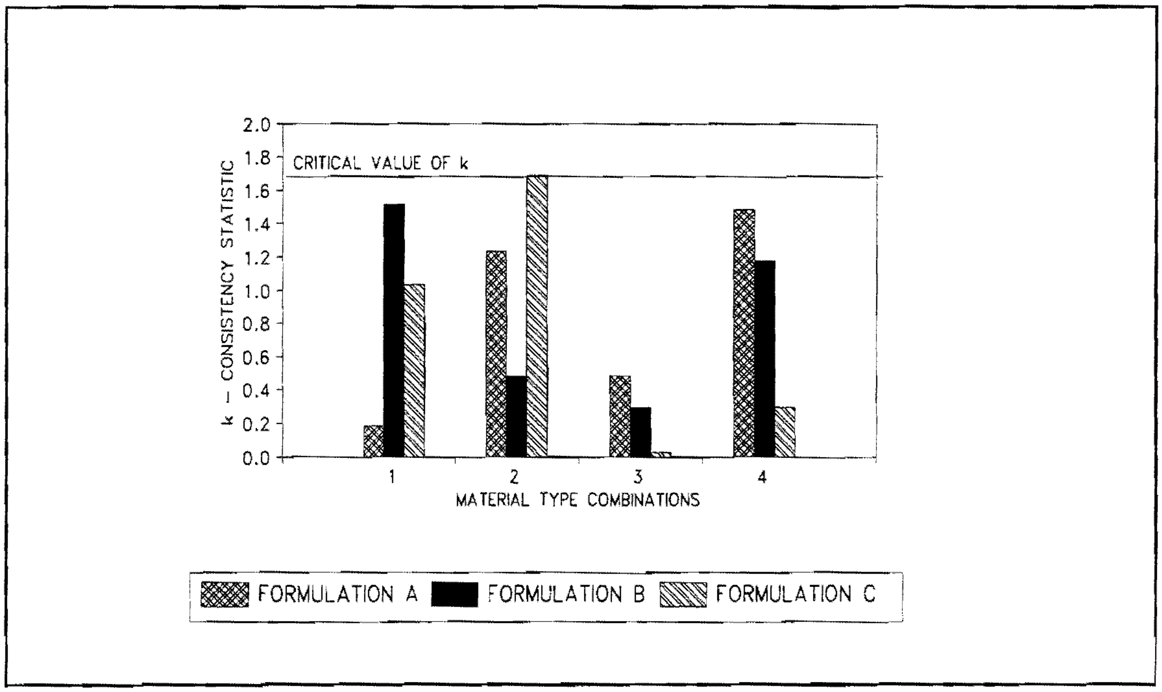

Figure 17. 6-day soak wet track abrasion test, k-consistency statistic versus material type combinations

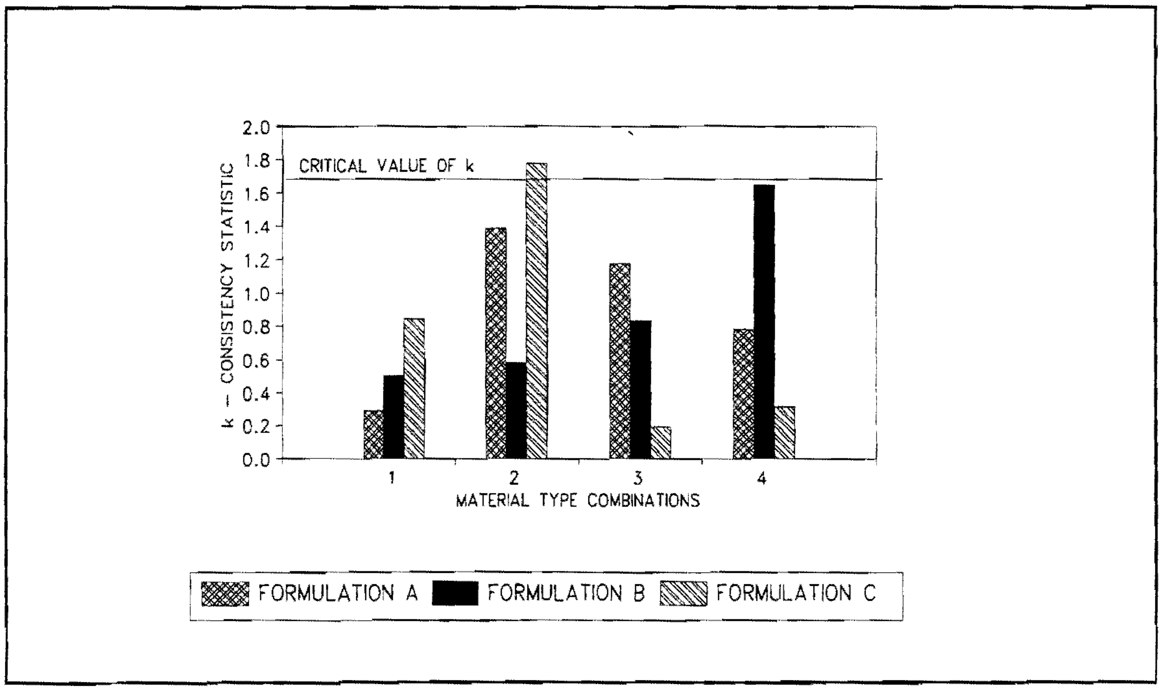

Figure 18. Loaded wheel test, plot of k-consistency statistic versus material type combinations

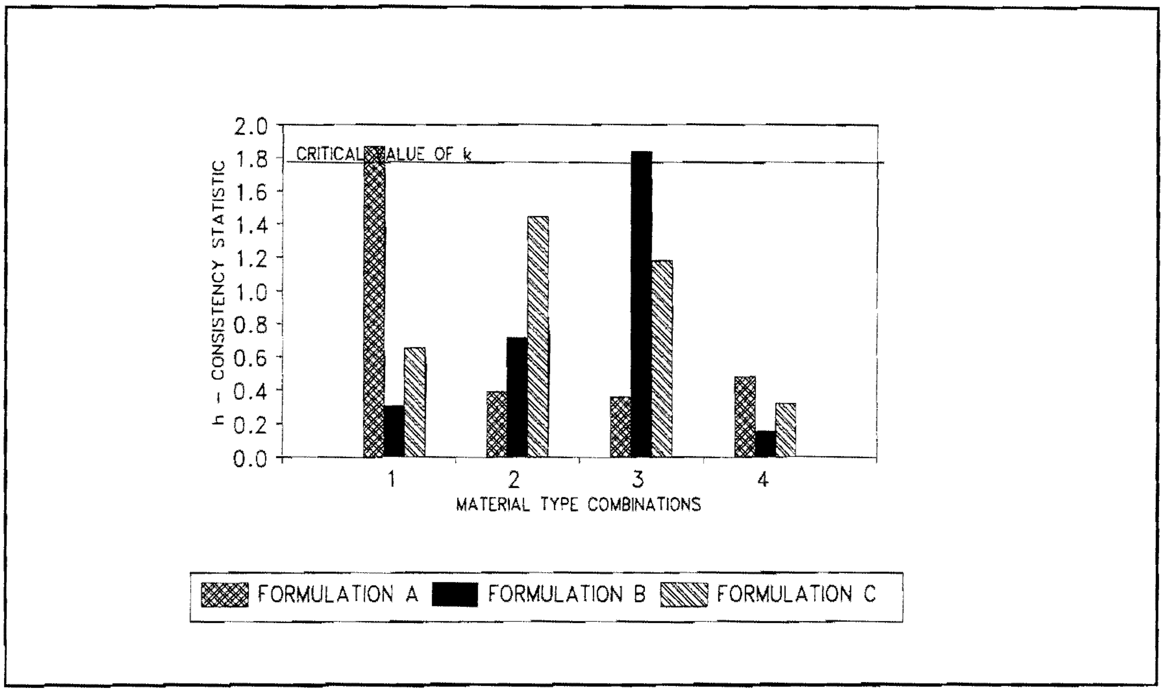

Figure 19. Schulze-Breuer and Ruck procedures (abrasion), plot of k-consistency statistic versus material type combinations

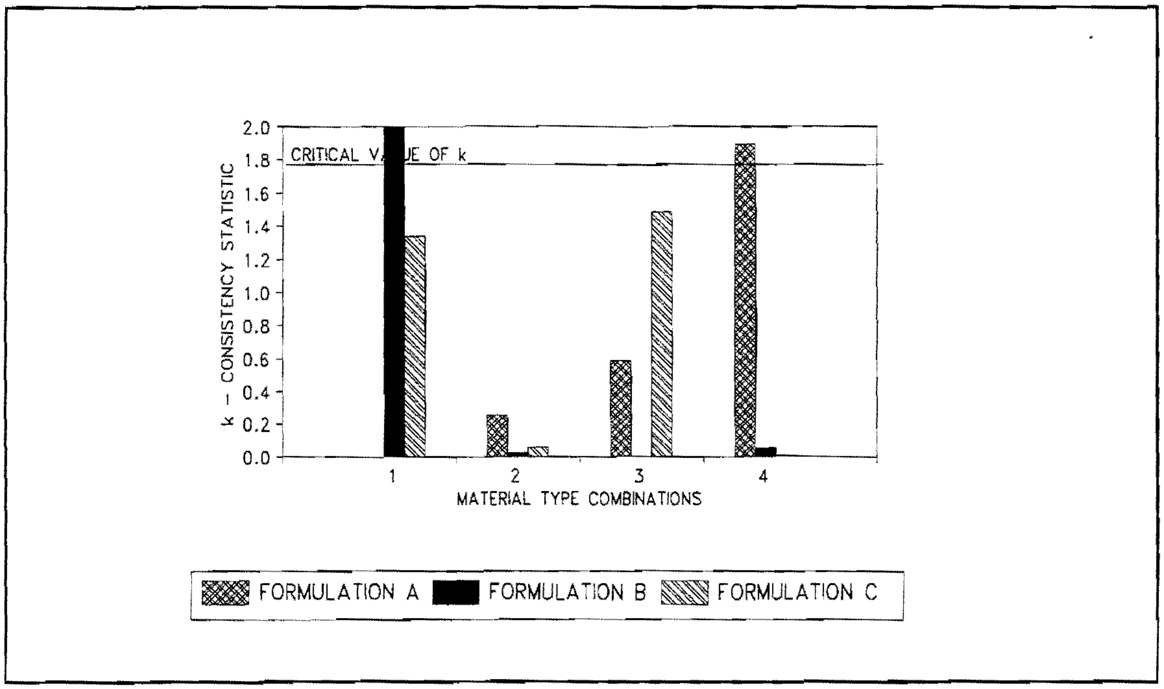

Figure 20. Schulze-Breuer and Ruck procedures (integrity), plot of k-consistency statistic versus material type combinations

combinations have substantially positive h values. The other figures generally show a balance of positive to negative among the combinations.

This suggests that there may be a test method vagueness that permits a wide range of interpretation. This wide range can lead to a loss of precision between different material combinations. Particular elements to be checked are measurement procedures, tolerances and insufficient direction for operator technique. These issues can form the basis for the revision of the test procedure and method (6).

k-Consistency Statistic

The values for the consistency statistic are evenly distributed between the different material combinations and the various formulations for all the cohesion tests, as shown in Figures 13 through 15. The values for k in Figure 16, which shows the k-consistency statistic for 1-hour soak wet track abrasion test are rather high for material combinations 1 and 2 but do not exceed the limits. However other combinations are low indicating that the results are sensitive to material combinations.

Figure 17 is a graph of the k-consistency statistic for various material combinations using the 6-day soak wet track abrasion test. The uneven distribution displayed in the graph indicates that the formulations used have a profound influence on the consistency of the results.

The critical values of k are exceeded in Figures 18 through 20. The k-consistency statistic is shown for the loaded wheel test in Figure 18. Figures 19 and 20 show the k-consistency statistic within material type combination for abrasion and integrity, respectively, using the Schulze-Breuer and Ruck procedures. Very small and extremely high k values are obtained with these tests. As previously stated, high k values represent within material imprecision and very small k values indicate an insensitive measurement scale or other measurement problem (6).

Precision Index Statements for Repeatability

In accordance with the preferred Indexes of Precision for ASTM test methods, the preferred index for repeatability is the Difference "Two" - Standard-Deviation Limits (d2s). This index is also known as 95 percent limit on the difference between two test results. This means that approximately 95 percent of all the pairs of test results are expected to differ in absolute value by less than $960 \sqrt{2}$, i.e, about 2.8s, where s is the Repeatability Standard Deviation. Therefore, the Index of Precision, r, or 95 percent Repeatability Limit is equal to 2.8Sr.

The underlying assumption is that the test results being compared are normally distributed. In this case, because the average of several test determinations is reported as a single test result, the assumption of normality is reasonable.

The 95 percent Repeatability Limit, r, is defined as the maximum difference in test response between two individual test results obtained under repeatability conditions. It may be expected to occur with a probability of approximately 0.95 (95 percent) (6). Precision Index Statements for the 95 percent Repeatability Limits for the ISSA tests investigated are given together with their test ranges in Table 20. The precision statistics obtained must not, however, be treated as exact as mathematical quantities which are applicable to all circumstances and uses. The Repeatability Limit should be considered as a general guide and the associated probability of 95 percent as only a rough indicator of what can be expected.

The coefficient of variation, C_v, for the ends of the test range for each test was computed. The coefficient of variation, C_v, is the standard deviation of a population expressed as a percentage of the mean. In this study, the population was each cell in which the experiment was repeated five times for a particular formulation. Tables 12 through 19 contain all the computed means and standard deviations for each cell. For the test range, the coefficient of variation is shown in Table 21. It illustrates the range of variability in data for each test performed.

The lower value repeatability limit corresponds to the left half of the mid-range average test response. The higher value repeatability limit corresponds to the right half of the average mid-range test response.

Table 21. ISSA tests precision index statements for the 95 percent repeatability limits

Test	Test Range (average)	C_v	95 Percent Repeatability Limit Within Material
Cured Cohesion Test (24-hours)	18.4 - 24.5 kg-cm	13.14 - 18.56	2.3 - 3.5 kg-cm
Modified Wet Cohesion Test (30 minutes)	7.4 - 19.1 kg-cm	6.16 - 7.64	2.3 - 5.1 kg-cm
Modified Wet Cohesion Test (60 minutes)	8.0 - 20.7 kg-cm	10.35 - 20.00	1.9 - 4.8 kg-cm
Wet Track Abrasion Test (1-hour soak)	14.0 - 1008.6 g/m^2 (1.3 - 93.6 g/ft^2)	37.67 - 286.22 (3.5 - 26.59)	253.0 - 1002.9 g/m^2 (23.5 - 93.17 g/ft^2)
Wet Track Abrasion Test (6-hour soak)	63.5 - 2576.7 g/m^2 (5.9 - 239.38 g/ft^2)	43.9 - 177.0 (4.08 - 16.44)	392.9 - 1166.8 g/m^2 (36.5 - 108.4 g/ft^2)
Loaded Wheel Test	582.3 - 1138.4 g/m^2 (54.1 - 105.76 g/ft^2)	61.7 - 107.9 (5.73 - 10.02)	242.2 - 605.2 g/m^2 (22.5 - 56.22 g/ft^2)
Schulze-Breuer and Ruck Procedures (abrasion)	0.262 - 4.212 g	2.13 - 3.49	1.08 - 1.84 g
Schulze-Breuer and Ruck Procedures (integrity)	0.0 - 99.6 %	undefined	15.83 - 99.77 %

CHAPTER 4
EFFECTS OF WATER, ADDITIVE, AND MINERAL FILLER ON TEST RESPONSES

GENERAL

The objective of the tests performed was to examine the effects of variations in quantity of portland cement, liquid additive, and water on the test results of specific micro-surfacing formulations using four test procedures. Additives or break retarders are usually supplied by the emulsion manufacturer. They are normally added to the mixture to control the set time of the micro-surfacing in the field. Type I portland cement is normally used as the mineral filler in micro-surfacing. Portland cement accelerates the break time of the emulsion in micro-surfacing mixtures. Portland cement may also act as a stiffener and an anti-strip agent in the mixture. The tests evaluated include:

- ISSA No. 139 : Method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics;

- ISSA No. 100 : Method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak;

- ISSA No. 109 : Method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion; and

- ISSA No. 144 : Method for the classification of aggregate filler-bitumen compatibility by Schulze-Breuer and Ruck procedures.

The effect on results from each test as variations were made in additive, mineral filler, and water quantities were examined and used to investigate observable trends. The objective in documenting the observed trends was to illuminate any fundamental interactions within material properties and quantities without examining the statistical significance of the results.

TEST PROCEDURES

All tests were performed on aggregate from Delta Materials. Table 22 presents the aggregate gradation. Figure 21 shows the gradation of the aggregate on a 0.45 power curve. Samples were made using 8, 10 and 12 percent Ergon CSS-1hP emulsion per 100 grams of aggregate. The emulsion contains 63 percent asphaltic cement residue, therefore, 5.04, 6.3, and 7.56 percent asphalt cement per 100 grams of aggregate. To reduce the variability in aggregate gradation, aggregate was carefully sieved and recombined to the specific gradation desired. The aggregate was separated into three main components, i.e.,

Table 22. Gradation for Delta Materials aggregate

Sieve Size, mm (English)	TxDOT Grade II Spec., % Retained	Job Mix Grading, % Retained
9.5 (3/8 in)	0 - 1	0.0
4.75 (#4)	6 - 14	7.9
2.36 (#8)	35 - 55	41
1.18 (#16)	54 - 75	59
0.6 (#30)	65 - 85	72.6
0.3 (#50)	75 - 90	83.1
0.15 (#100)	82 - 93	88.9
0.075 (#200)	85 - 95	93.4

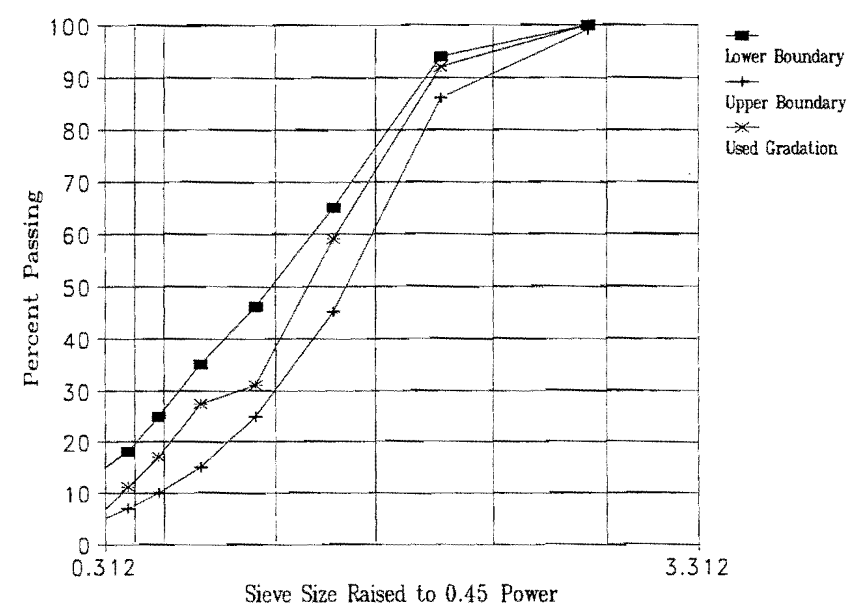

Figure 21. Gradation of Delta Materials aggregate on 0.45 power curve

material retained on the 4.75 mm (No. 4) sieve, material passing the 4.75 mm (No. 4) sieve but retained on the 2.36 mm (No. 8) sieve and material passing the 2.36 mm (No. 8) sieve. For modified cohesion and loaded wheel tests, aggregates were recombined to produce 300 gram batches. For wet track abrasion tests, recombination was done in 700 gram batches. Schulze-Breuer and Ruck tests used the recombined aggregate passing the 2.00 mm (No. 10) sieve.

Type I lump free portland cement was used as the mineral filler. Mixtures containing 0.25, 0.75, and 1.5 percent portland cement were used. Ergon supplied, set retardant, an emulsifying agent normally referred to as "additive" was investigated. A full factorial of mixtures with two additive concentrations of 0.05 percent and 0.1 percent was performed. Table 23 shows the factorial experiment. Some mixtures were made without additive.

The additive was introduced into the sample by preparing volumetric concentrations with the distilled water. For each percentage of additive, the required amount of distilled water containing additive was added to the sample mixture.

The following example shows how a wet track abrasion sample with the formulation 12 percent water, 12 percent emulsion, 0.75 percent portland cement, and 0.05 percent additive was prepared. Seven hundred grams of aggregate was weighed out. A portion of cement, 5.25 (0.75 x 7) grams, was added to the aggregate and thoroughly mixed. Using 840 grams of distilled water, a dropper was used to add 0.05 x 7 x 10 grams of additive to the distilled water. Calculations are simplified by using 840 grams. It is the amount of water required to make 10 wet track abrasion samples using 700 grams and 12 percent water per 100 grams. The solution formed was always thoroughly shaken before use. A portion of solution weighing 84 + (0.05 x 7) grams was added to the aggregate cement mixture and thoroughly blended. After that, 84 grams of emulsion was added to the mixture and stirred thoroughly.

ANALYSIS OF RESULTS

The results were analyzed by plotting the primary responses for the four tests on the abscissa and either amount of additive, filler material, or water on the ordinate. Table 24 shows the primary response and significance for each test. The compatibility classification system for the Schulze-Breuer and Ruck procedures is given in Table 25. All required minimum and maximum values are determined as the average of three replicate tests.

In this study, the tests were not used in the selection of optimum asphalt content, but rather to investigate the effect of mineral filler and water increments, as well as the incorporation of additive on the performance of micro-surfacing mixtures. The effect of variations in the water content of the mixture was investigated for the modified and cured cohesion tests, loaded wheel tests, and the 6-day wet track abrasion test. In the case of the

Table 23. Experimental design for the impact of material variation

Cement Content		0.25%			0.75%			1.5%		
Test	Water Content % / Additive	8	10	12	8	10	12	8	10	12
Cohesion	None 0 %	X	X	X	X	X	X	X	X	X
	Moderate 0.05	X	X	X	X	X	X	X	X	X
	High 0.1 %	X	X	X	X	X	X	X	X	X
Wet Track	None 0 %	X	X	X	X	X	X	X	X	X
	Moderate 0.05	X	X	X	X	X	X	X	X	X
	High 0.1 %	X	X	X	X	X	X	X	X	X
Loaded Wheel	None 0 %	X	X	X	X	X	X	X	X	X
	Moderate 0.05	X	X	X	X	X	X	X	X	X
	High 0.1 %	X	X	X	X	X	X	X	X	X
Schulze-Breuer and Ruck	None 0 %			X			X			X
	Moderate 0.05			X			X			X
	High 0.1 %			X			X			X

Schulze-Breuer tests, investigations to observe trends were performed only with mixtures containing 12 percent asphalt emulsion or 7.56 percent asphalt cement. During previous tests, highly inconsistent results were obtained with mixtures containing less than 12 percent asphalt emulsion.

Table 24. Primary response and significance for mixture design tests

TEST	PRIMARY RESPONSE	SIGNIFICANCE
Modified Cohesion Tests (Wet and Cured)	Cohesion in kg-cm as measured by torque wrench with minimum torque of 12 kg-cm at 30 minutes and 20 kg-cm at 60 minutes and after 24 hours cure, a minimum of 24 kg-cm (5).	Selects minimum mineral filler content
Wet Track Abrasion 1-Hour soak	Abrasion loss maximum value after 1-hour of soaking of 538 g/m^2 (50 g/ft^2) (5)	Selects the minimum asphalt content
Wet Track Abrasion 6-day soak	Abrasion loss maximum value after 6-days of soaking of 807 g/m^2 (75 g/ft^2) (5)	Acts as check for moisture susceptibility for selected asphalt content
Loaded Wheel Test	Sand adhesion of 807 g/m^2 (75 g/ft^2) is the maximum allowed.(5)	Establishes maximum asphalt content

Table 25. Compatibility classification system for Schulze-Breuer and Ruck procedures (5)

Grade Rating Each Test	Point Rating Each Test	Abrasion Loss, grams	Integrity 30 minute boil, % Retained	Adhesion 30 minute boil, % Coated
A	4	0 - 0.7	90 - 100	90 - 100
B	3	0.7 - 1.0	75 - 90	75 - 100
C	2	1.0 - 1.3	50 - 75	50 - 75
D	1	1.3 - 2.0	10 - 50	10 - 50
0	0	2.0 +	0	0

Wet Cohesion Test (30 minutes)

Figure 22 is a plot of raw data for wet cohesion values at 30 minutes versus additive amounts at 8 percent water content. As additives are added to low water mixtures, there is a continuous reduction of cohesion for mixtures with low cement contents of 0.25 percent. For low water content systems with greater than 0.05 percent additive, acceptable cohesion values can only be achieved when there is a high amount of mineral filler in the system. Preferably, greater than 0.75 percent mineral filler should be used.

Figure 23 is a plot of raw data for wet cohesion values at 30 minutes versus mineral filler with 8 percent water content. This water content is considered a low amount of water in the mixture. From the graph, it can be inferred that when there is no additive in systems with low water contents, minimum cohesion values of 12 kg-cm can be achieved for all filler amounts. In such systems, increasing the mineral filler results in higher cohesion values.

Figure 24 is a plot of raw data for wet cohesion values at 30 minutes versus additive amounts at 10 percent water content. The graph shows that with 10 percent water content systems, addition of very small amounts of additive leads to a drop in cohesion values. The test cannot discern between mineral filler amounts of 0.25 percent and 0.75 percent. When the need arises to use small amounts of additive, that is, less than 0.05 percent additive, high amounts of mineral filler should be used to achieve acceptable results.

Figure 25 is a plot of raw data for wet cohesion values at 30 minutes versus mineral filler with 10 percent water content. There is a uniformity of trends, depicted by mixture systems containing 10 percent water. Perhaps that is an indication that mixture system material interactions are critically dependent on having a specific amount of water. The graph shows that there is a very slight increase in cohesion values as the mineral filler amount increases. Mixtures with the smallest amounts of additive have the highest cohesion values. However, only systems without any additive have cohesion values above the minimum at 30 minutes. It shows that higher concentrations of additive reduce cohesion values at 30 minutes indicating that they increase the set time. An amount of 0.1 percent additive gave the lowest cohesion values. At 30 minutes, 0.1 percent additive and 1.5 percent mineral filler do not meet the minimum acceptable criteria of 12 kg-cm. With zero percent additive, adequate cohesion values are achieved at 30 minutes.

Figure 26 shows 30 minutes wet cohesion values are a function of additive amounts with 12 percent water. As the additive is increased above 0.05 percent, the cohesion values decrease for all mineral filler contents. The threshold value of 0.05 percent additive is clearly shown. At additive concentrations below 0.05 percent, cohesion values increase with increase in mineral filler. To achieve a minimum cohesion value of

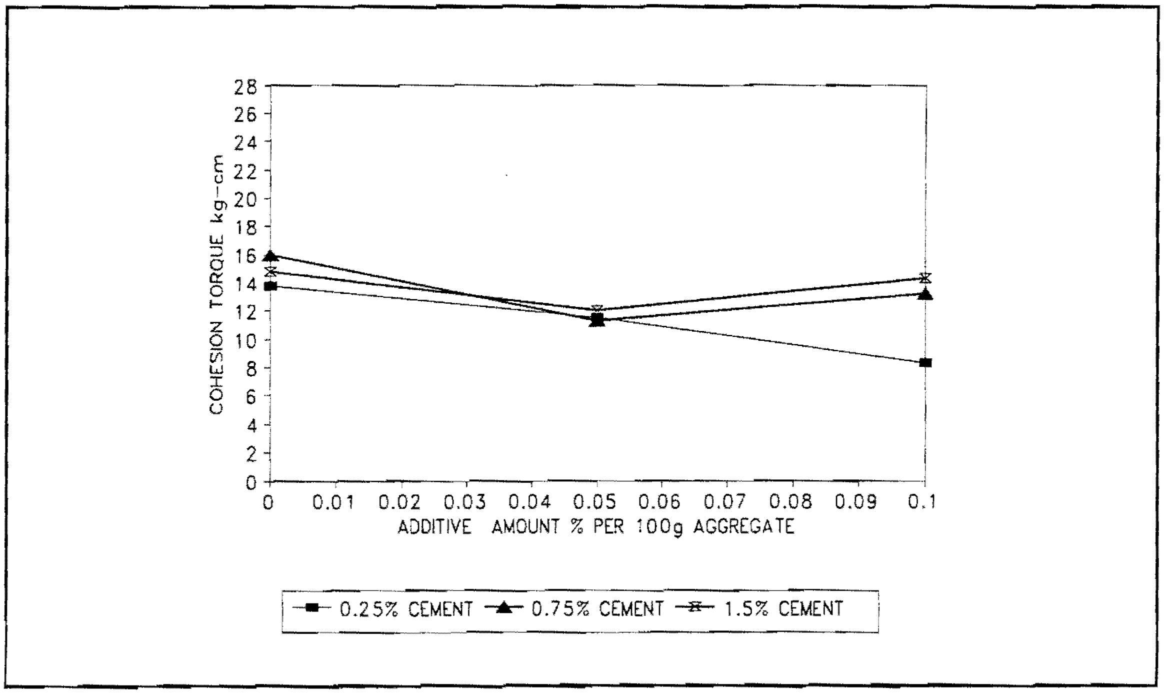

Figure 22. 30-minute wet cohesion torque values against additive amounts with 8 percent water

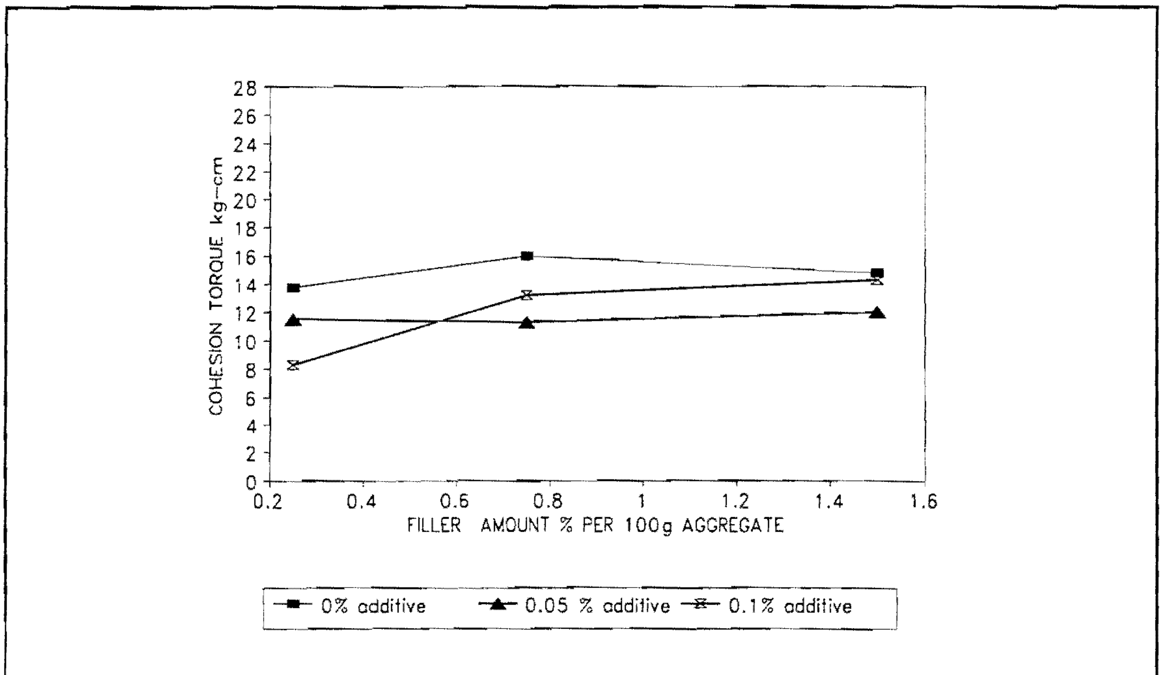

Figure 23. 30-minute wet cohesion torque values against mineral filler with 8 percent water

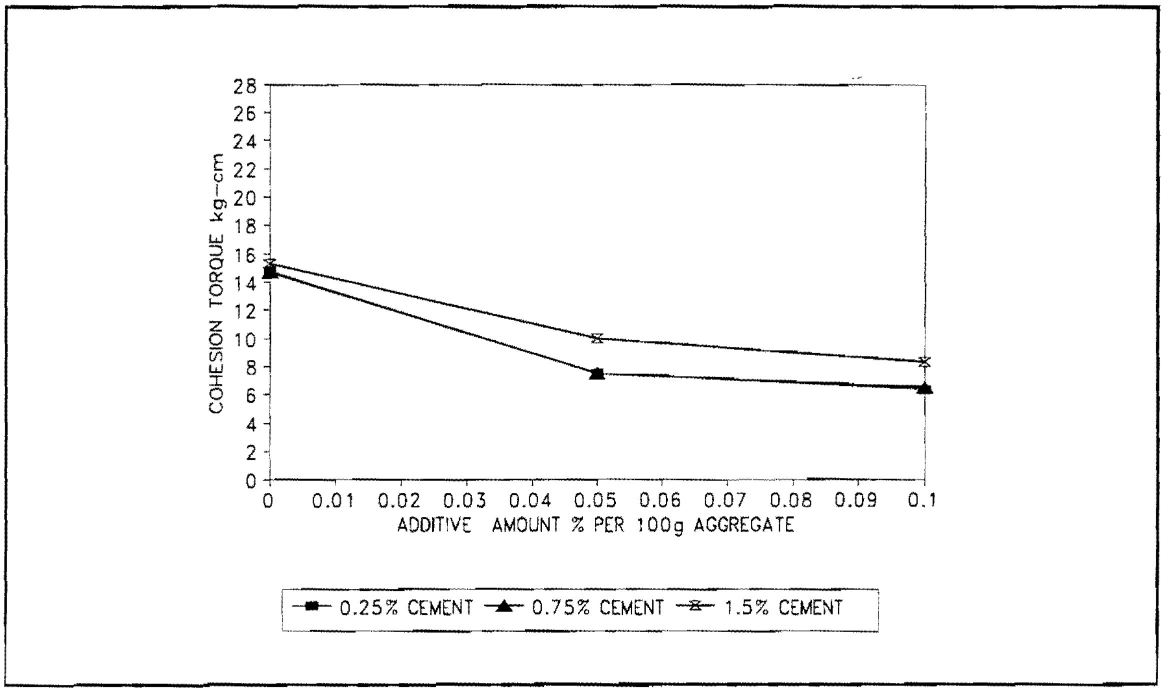

Figure 24. 30-minute wet cohesion torque values against additive amounts with 10 percent water

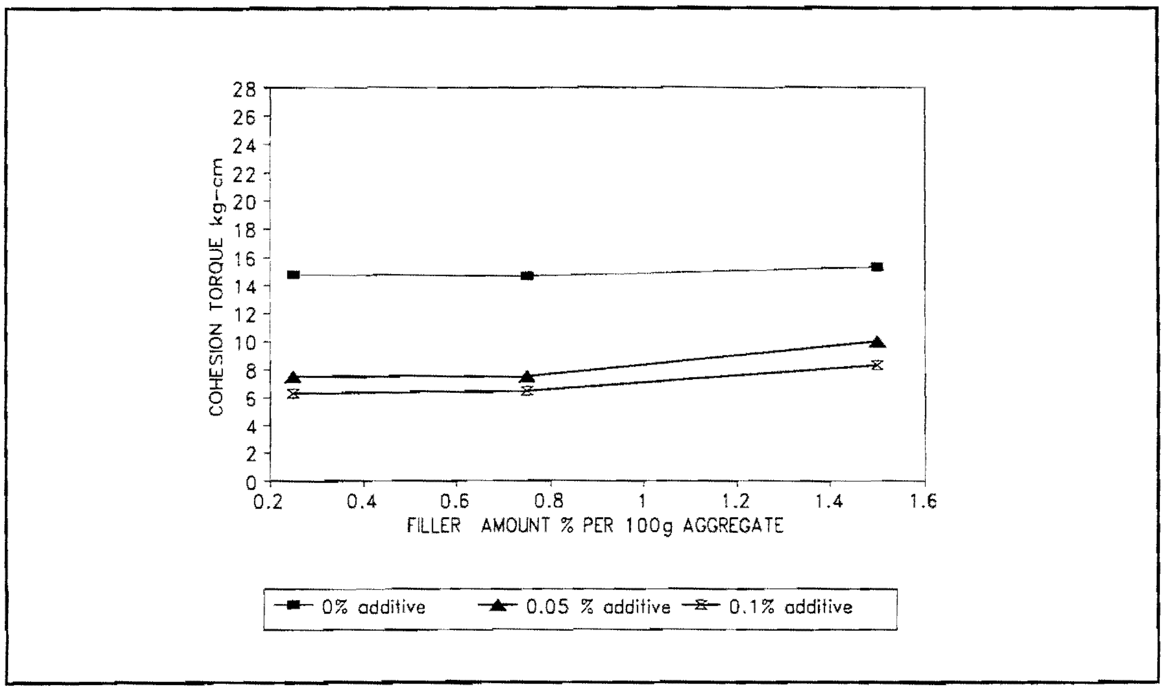

Figure 25. 30-minute cohesion torque values against mineral filler with 10 percent water

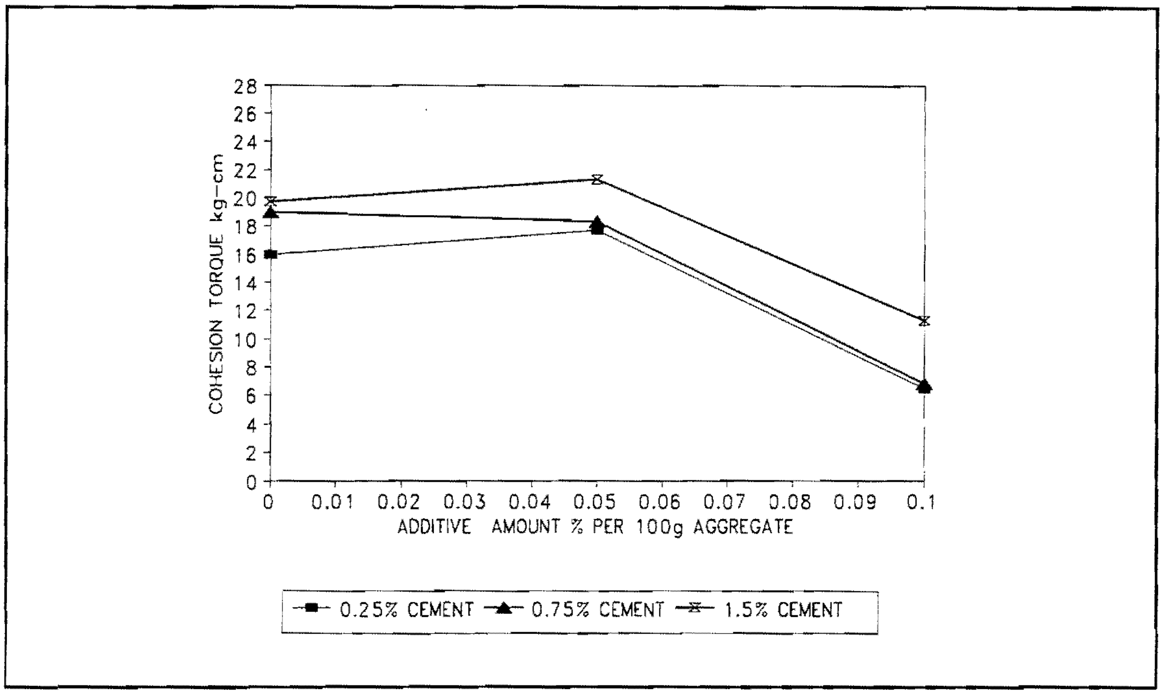

Figure 26. 30-minute wet cohesion torque values against additive amounts with 12 percent water

12 kg-cm at 30 minutes, it is suggested that additive amounts added to any system of mixtures with 12 percent water content should not be greater that 0.05 percent.

Figure 27 is a plot of raw data for wet cohesion values at 30 minutes versus mineral filler amount with 12 percent water. It shows that higher concentrations of additive reduce cohesion values at 30 minutes indicating that the set time is increased. An amount of 0.1 percent additive has the lowest values. At 30 minutes, 0.1 percent additive and 1.5 percent mineral filler, do not meet the minimum acceptable criteria of 12 kg-cm. With zero and 0.05 percent additive, adequate cohesion values are achieved at 30 minutes. With the addition of additive, cohesion values are relatively stable at mineral filler amounts below 0.75 percent, but at mineral filler amounts higher than 0.75 percent cohesion values increase more rapidly. This trend is inverted in mixtures without any additive. For systems containing no additive there is an increase in cohesion values below 0.75 percent mineral filler which stabilizes as mineral filler is increased beyond 0.75 percent.

Figure 28 is a plot of 30- minute cohesion values for mixture systems with zero percent additive versus water content. All values were greater than the minimum acceptable value of 12 kg-cm. The general trend is that cohesion values are relatively stable as water content is increased from low water contents of 8 percent to medium values of 10 percent. The system becomes more sensitive to water addition as the water content is increased to 12 percent, with all samples showing a slight gain in cohesion. The amount of mineral filler has little effect.

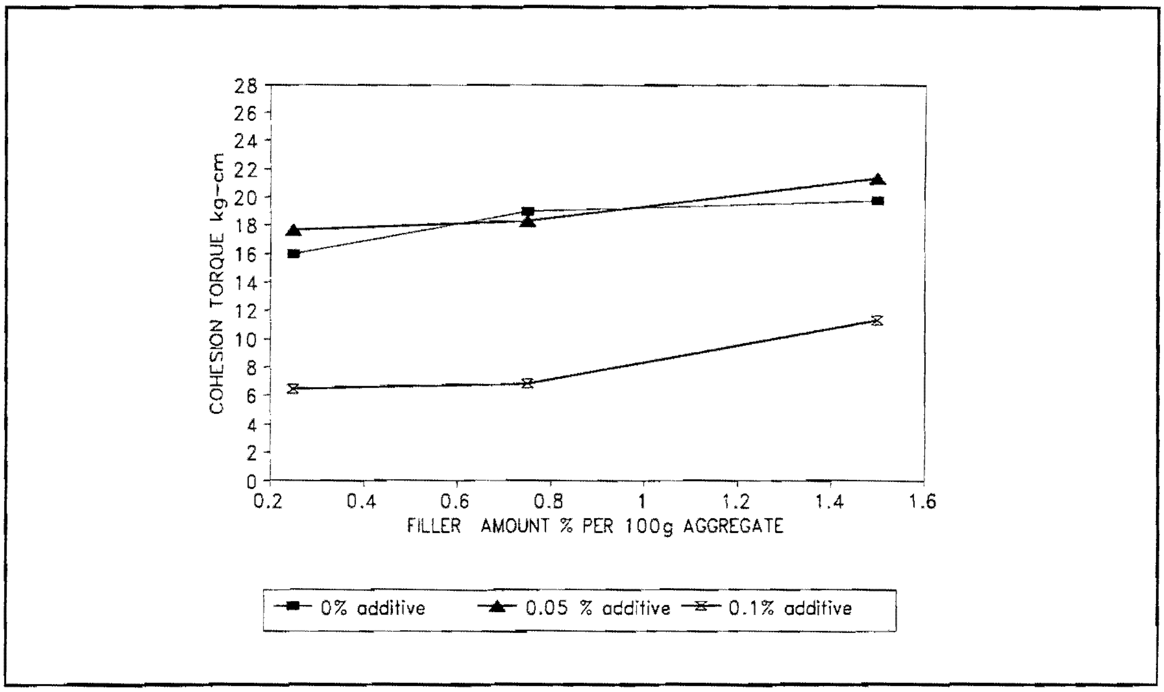

Figure 27. 30-minute wet cohesion torque values against mineral filler with 12 percent water

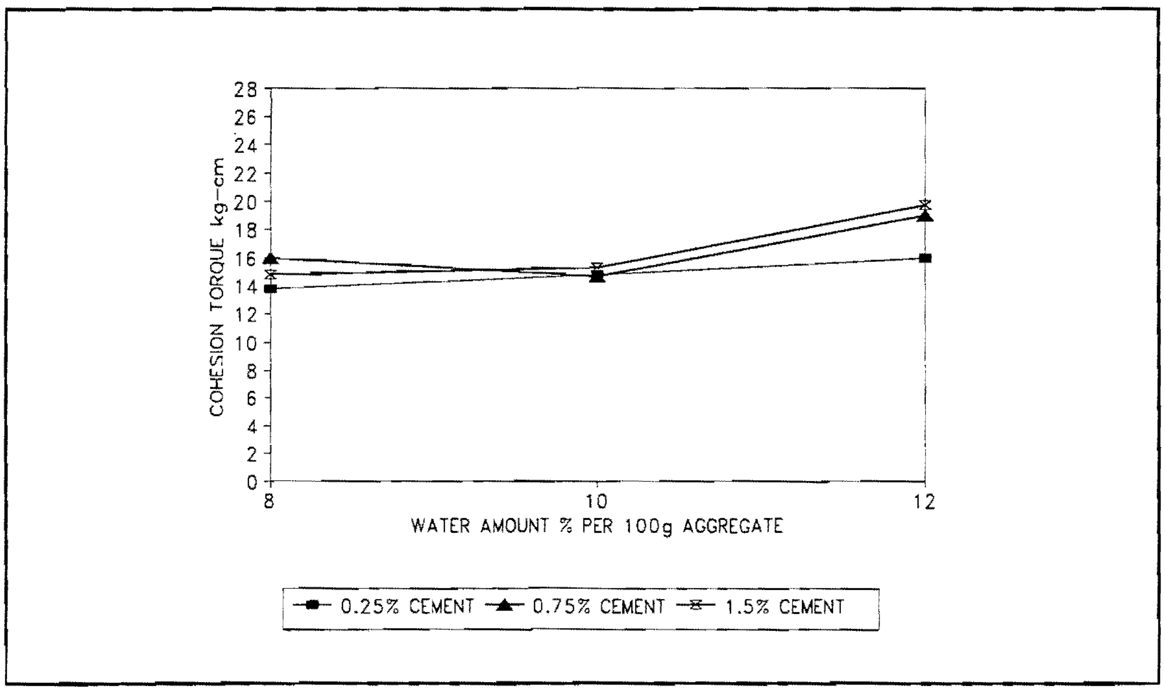

Figure 28. 30-minute cohesion torque values against water content with 0 percent additive addition

Figure 29 is a plot of cohesion values at 30 minutes for mixture systems with 0.05 percent additive versus water content. The graph shows that there is a slight decrease in cohesion as water content is increased from 8 percent to 10 percent and an increase as the water content is further raised to 12 percent. For all water contents, 1.5 percent mineral filler content has the greatest cohesion value. For mixture systems containing 0.05 percent additive to achieve acceptable cohesion results, it is advisable to use greater than 1.5 percent mineral filler.

Figure 30 is a plot of cohesion values at 30 minutes for mixture systems with 0.1 percent additive versus water content. The graph shows that with mixtures containing high additive concentrations, the highest cohesion is achieved when the mixture has the least amount of water. The cohesion then decreases as water is added to the system and then increases slightly as water is increased again. For high additive content systems, it is clear that larger cohesion values are obtained with high mineral filler content mixtures.

Overall, water content and additive had the largest effect on 30-minute cohesion test results. This indicates that we need a method to define a water content at which tests should be conducted.

60-Minute Wet Cohesion Test

Figure 31 shows a plot of raw data for wet cohesion values at 60 minutes versus additive amounts at 8 percent water. The highest cohesion values are achieved by mixtures without any additive at low water contents. Acceptable cohesion values are obtained when 0.75 percent mineral filler is used with zero percent additive at low water contents of 8 percent. A comparison of Figure 22 with Figure 31 shows similar trends; the difference is that cohesion values are greater at 60 minutes testing. However, it must be noted that there is not a uniform increase in cohesion for all additive levels and mineral filler content. The largest cohesion increments at 60 minutes compared to the mixtures at 30 minutes testing occur in mixtures with no additive and 0.75 percent mineral filler. The smallest increments occur within systems with 0.75 percent mineral filler and the highest additive addition of 0.1 percent. This shows that mixtures with low water contents are very sensitive to the amount of additive added in achieving higher cohesion values over time.

Figure 32 is a plot of raw data for wet cohesion values at 60 minutes versus mineral filler amounts at 8 percent water content. The trend depicted indicates that increasing mineral filler leads to slightly higher cohesion values for all additive amounts in the mixture. However, cohesion values obtained fall below the acceptable value of 20 kg-cm for all the mixtures.

Figure 33 shows a plot of raw data for wet cohesion values at 60 minutes versus additive amount at 10 percent water. Adequate cohesion values are obtained only with mixtures containing low amounts of additive, irrespective of the mineral filler content. As the additive amounts are increased beyond 0.05 percent, cohesion is reduced for all mineral filler amounts. Comparing Figure 33 to Figure 31, it appears that trends are inverted. This implies that for each mixture system with a specific amount of water, there

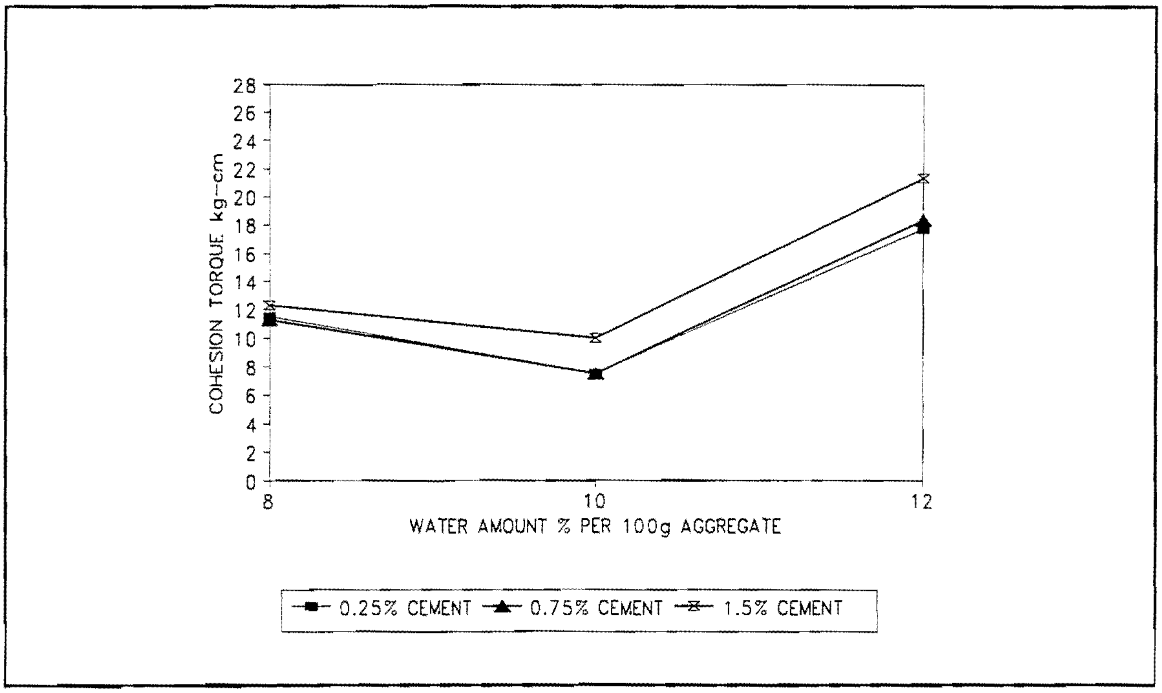

Figure 29. 30-minute wet cohesion torque values against water content with 0.05 percent additive addition

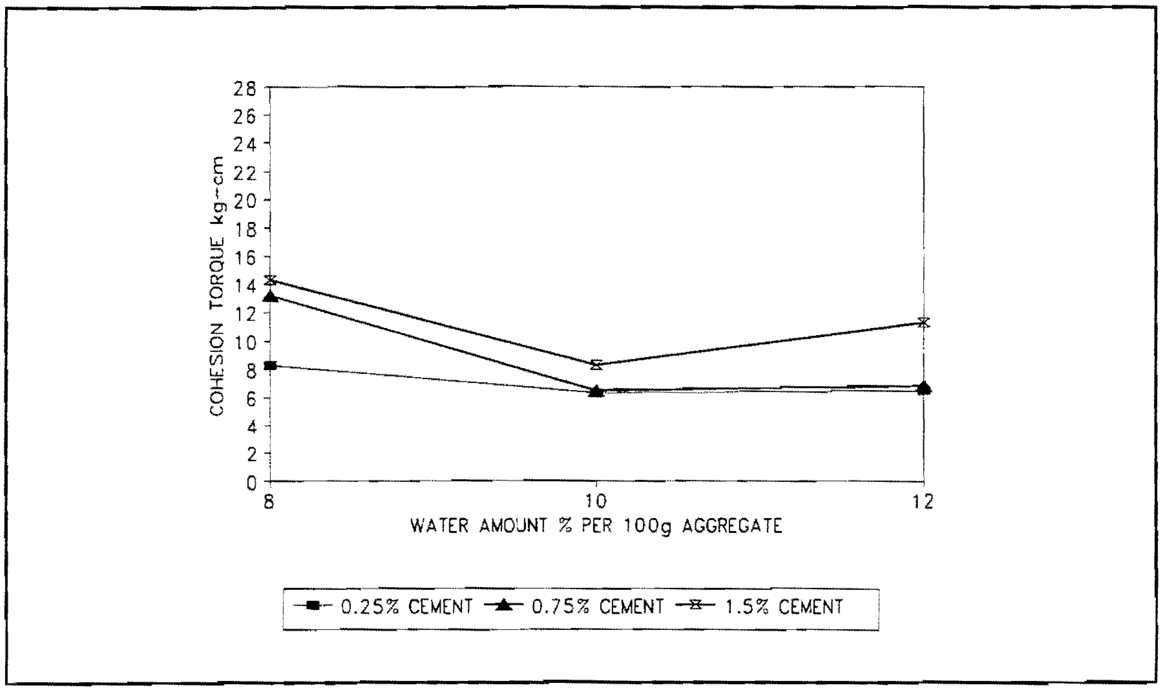

Figure 30. 30-minute wet cohesion torque values against water content with 0.1 percent additive addition

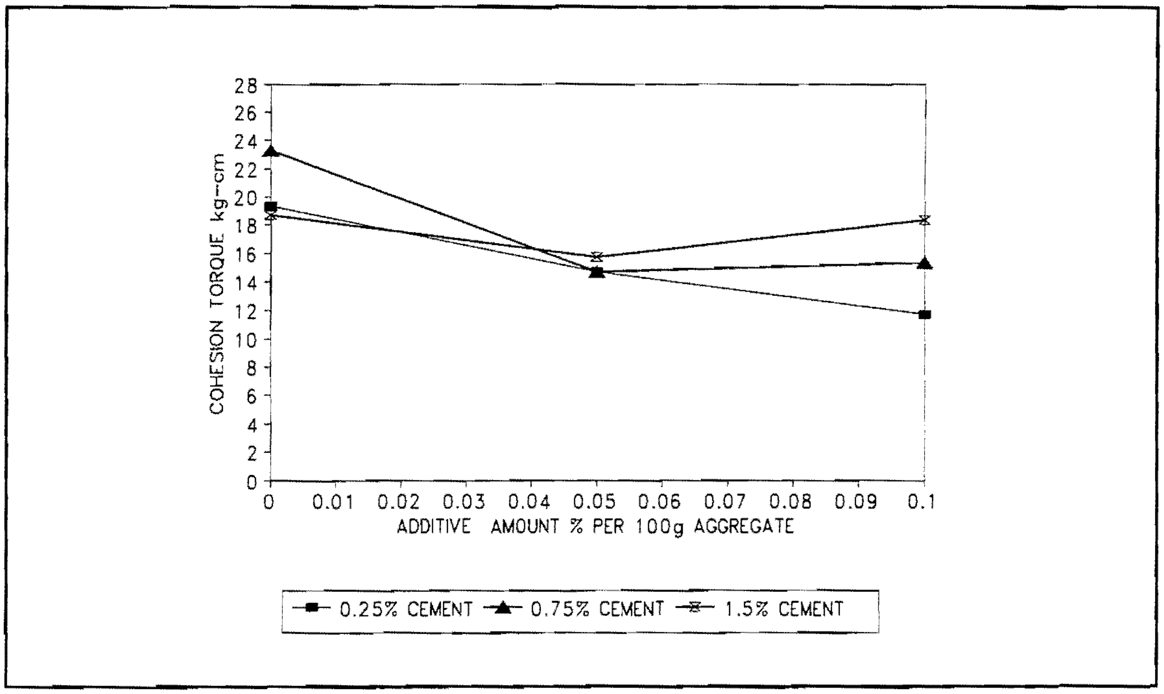

Figure 31. 60-minute wet cohesion torque values against additive amounts with 8 percent water

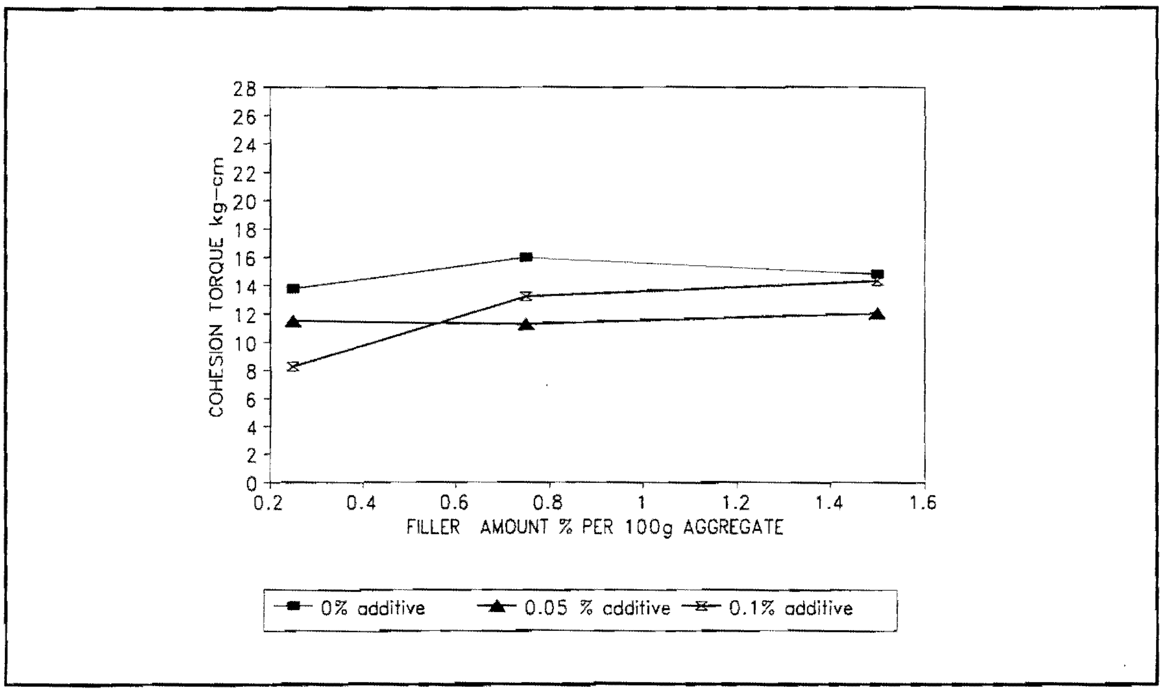

Figure 32. 60-minute wet cohesion torque values against mineral filler with 8 percent water

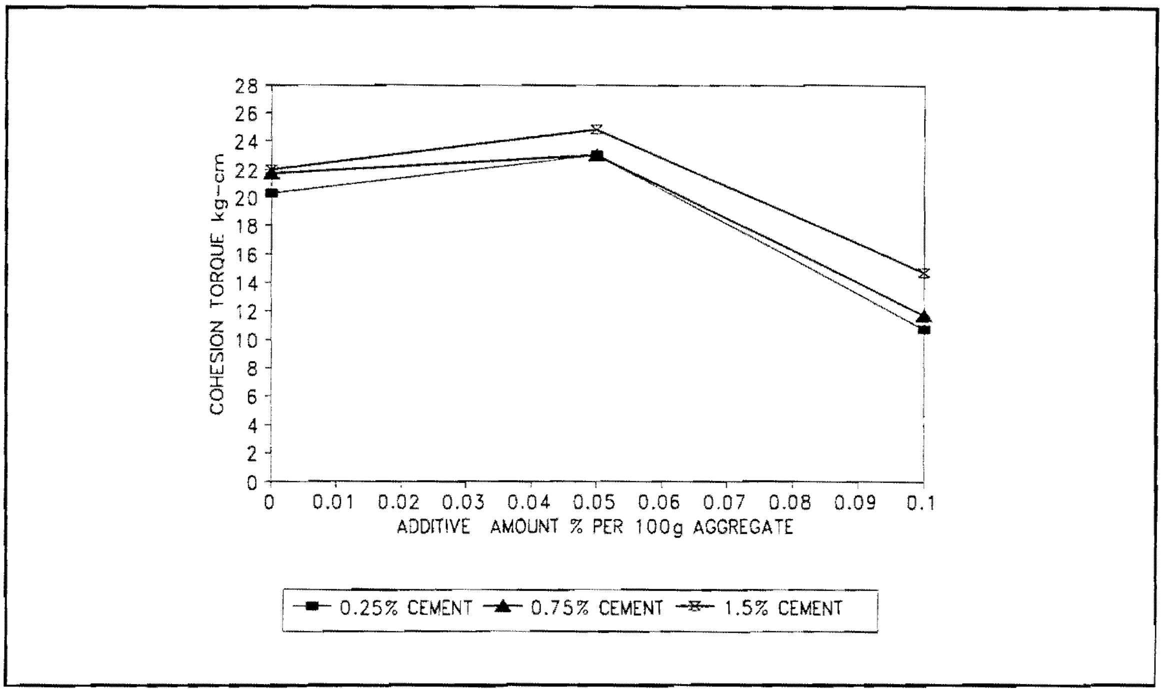

Figure 33. 60-minute wet cohesion torque values against additive amounts with 10 percent water

is an optimal amount of additive which must be added to the mixture to achieve adequate cohesion. From the graphs, it can be inferred that the smaller the amount of water the greater the optimal amount of additive, and that mixtures with more water require less additive.

Figure 34 shows a plot of raw data for wet cohesion values at 60 minutes versus mineral filler content at 10 percent water. The somewhat uniform trend observed suggests that the smaller the additive amount in the mixture, the greater the cohesion achieved for the mixture. For each set of mixtures at a particular additive content, there is a very slight decrease in cohesion as mineral filler is increased to 0.05 percent. Then, an increase occurs as the mineral filler content is further increased. The greatest increment occurs with mixtures containing 0.05 percent additive and the least with mixtures containing 0.1 additive. Comparing Figure 34 to 32, the picture depicted shows that with a slight increase in water content the spread in cohesion values is greater for all mixtures.

Figure 35 is a raw data plot of cohesion as a function of additive amounts. The threshold values of 0.05 percent additive appear to be a point after which there is a rapid decrease in cohesion values for all mineral filler contents. Perhaps this is an indication that for mixtures containing 12 percent water, the maximum amount of mineral filler used should be around 0.05 percent. Comparing Figure 35 to Figures 33 and 31, it is evident that there is no gain in cohesion value by further increasing water from 10 percent to 12 percent. Rather, with high additive concentrations, a slight decrease in cohesion is

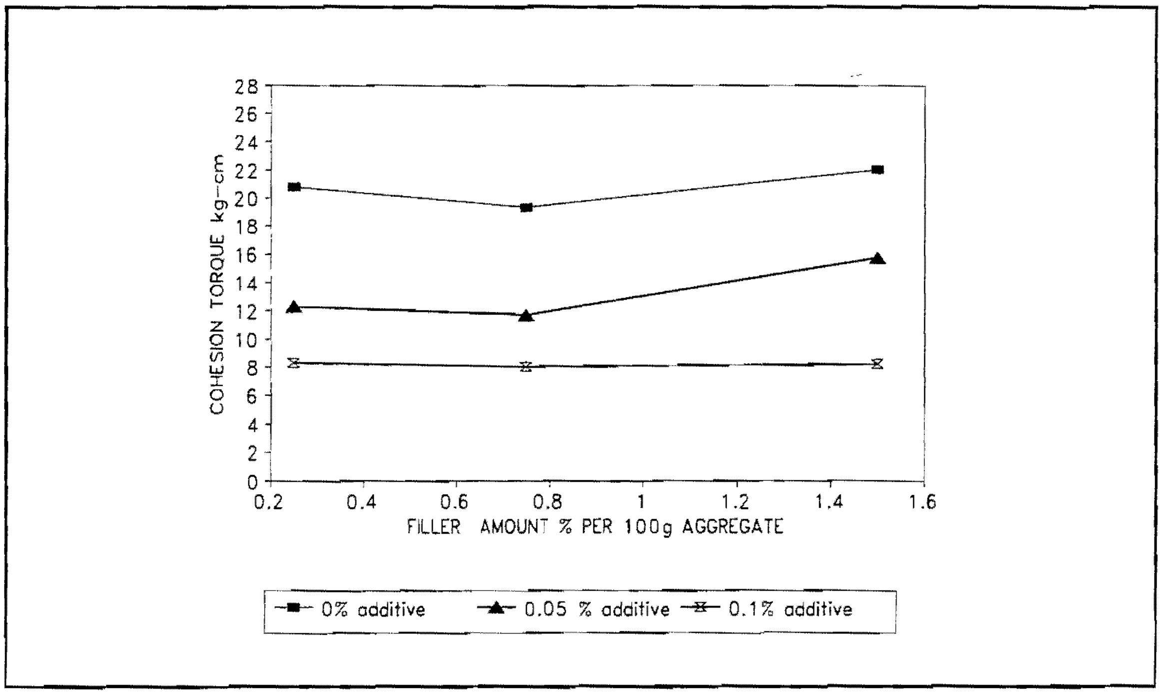

Figure 34. 60-minute cohesion torque values against mineral filler with 10 percent water

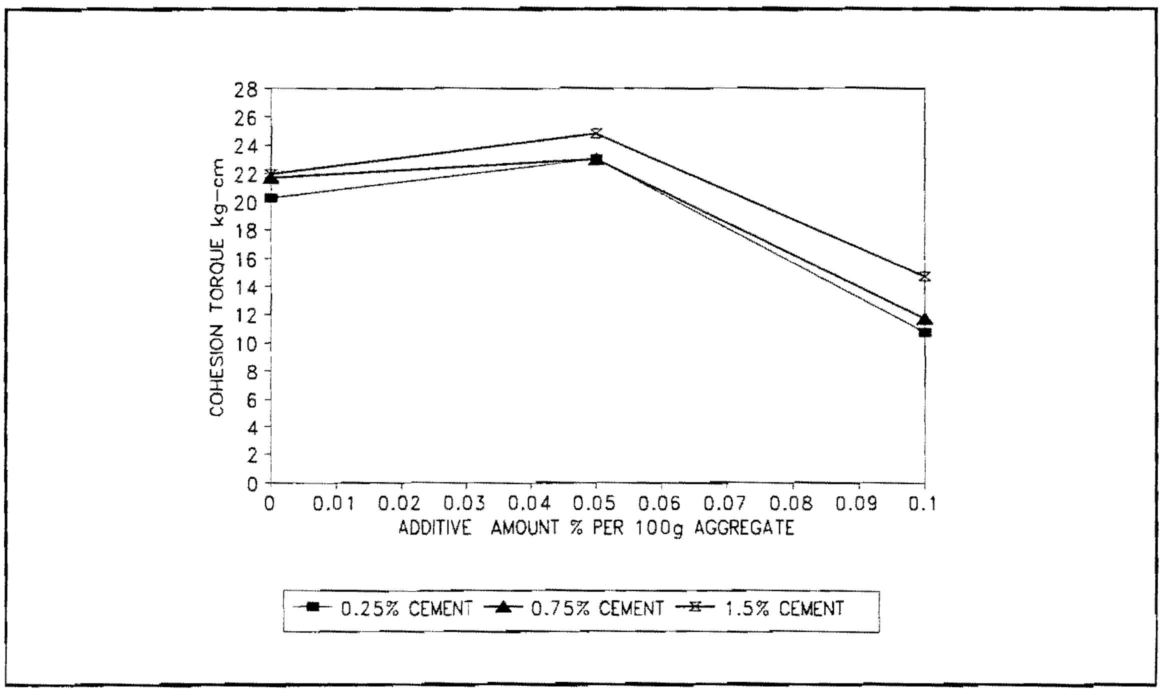

Figure 35. 60-minute wet cohesion torque values against additive amounts with 12 percent water

recorded. The implication is that, when adequate cohesion has been achieved in a mixture without any additive, slight increases in water content do not substantially affect cohesion values. However, with mixtures containing additive and moderate to high amounts of water, if acceptable cohesion values are obtained, further increases in additive will lower the cohesion achieved.

Figure 36 shows cohesion at 60 minutes as a function of mineral filler amount. The fundamental difference worth noting between this graph and Figure 26 is that higher cohesion values are observed. A slight inflection point can still be discerned in the graphs at 0.75 percent mineral filler. A comparison of the gradient at 60 minutes to 30 minutes (refer to Figure 26) shows strength gain is slowing in all the mixtures. Comparing Figure 36 to Figures 32 and 34, it appears that higher cohesion is realized for all mineral filler amounts as water content is increased with mixtures containing no to moderate amounts of additive.

Figure 37 is a graph of cohesion values versus water content without any additive addition. This graph shows that when there is no additive in the mixture, cohesion values are not significantly affected by increments in water at 60 minutes testing.

Figure 38 is a graph of cohesion values versus water content with 0.05 percent additive addition. The plot shows that there is a rapid increase in cohesion values as water in the mixture is increased beyond 10 percent.

Figure 39 is a graph of cohesion values versus water content with 0.1 percent additive addition. As water contents are increased, from 8 percent to 10 percent, there is initially a lowering of cohesion values. Cohesion is increased as the water content is further increased to 12 percent. The same phenomenon is observed with 0.05 percent additive content mixtures. The increase occurs much more rapidly in mixtures with 0.05 percent additive when the water content shifts from 10 to 12 percent. When the water content shifts from 8 to 10 percent, the increase in cohesion is more rapid in mixtures with 0.1 percent additive.

Again, additive and water content have a large impact on the test results. Cement seems to only have some effect at higher additive levels.

24-Hour Cured Cohesion Data

With this test, the mineral filler amount that will identify the mixture with the greatest cohesion value over time can be chosen. The ISSA design technical bulletin, (5) test No. 139 states that solid spin should be considered as having an equivalent cohesion value of 26 kg-cm. However, the real values recorded with the wrench were used to generate the curves.

Figures 40 and 41 are plots of cohesion values after 24 hours curing versus additive amount and mineral filler, respectively, for mixtures with a low a water content of 8 percent. Figure 40 shows the spread in cohesion values. The spread shows that mixture systems with low water contents have similar values after 24 hours of curing.

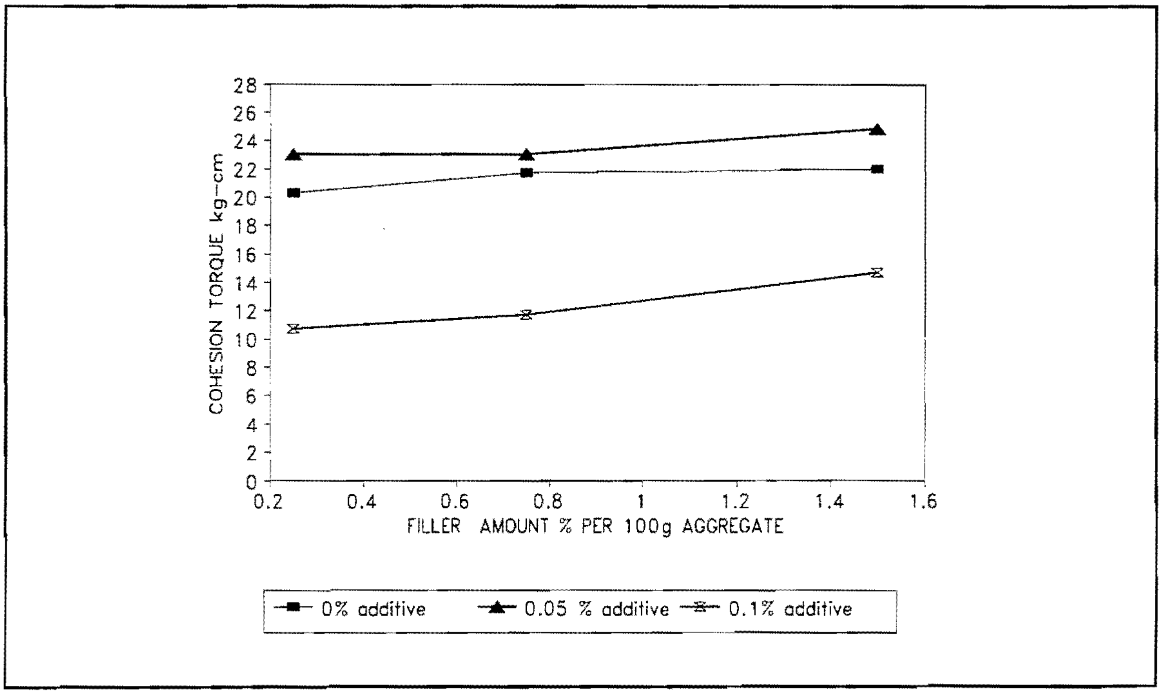

Figure 36. 60-minute wet cohesion torque values against mineral filler with 12 percent water

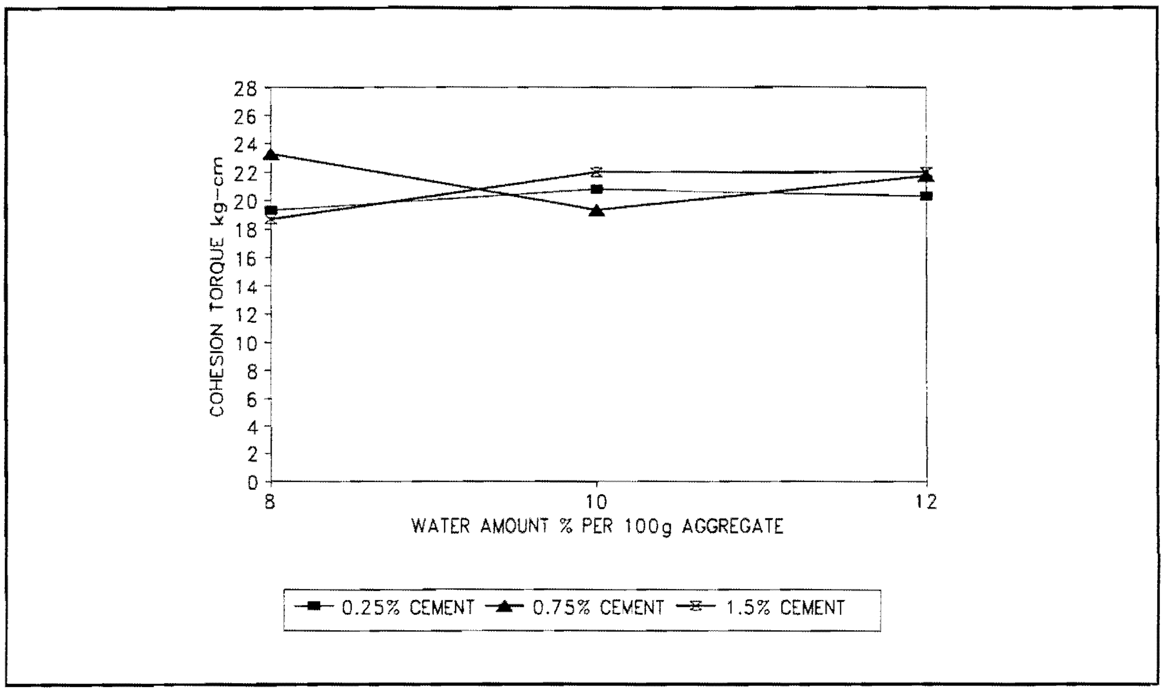

Figure 37. 60-minute cohesion torque values against water content with 0 percent additive addition

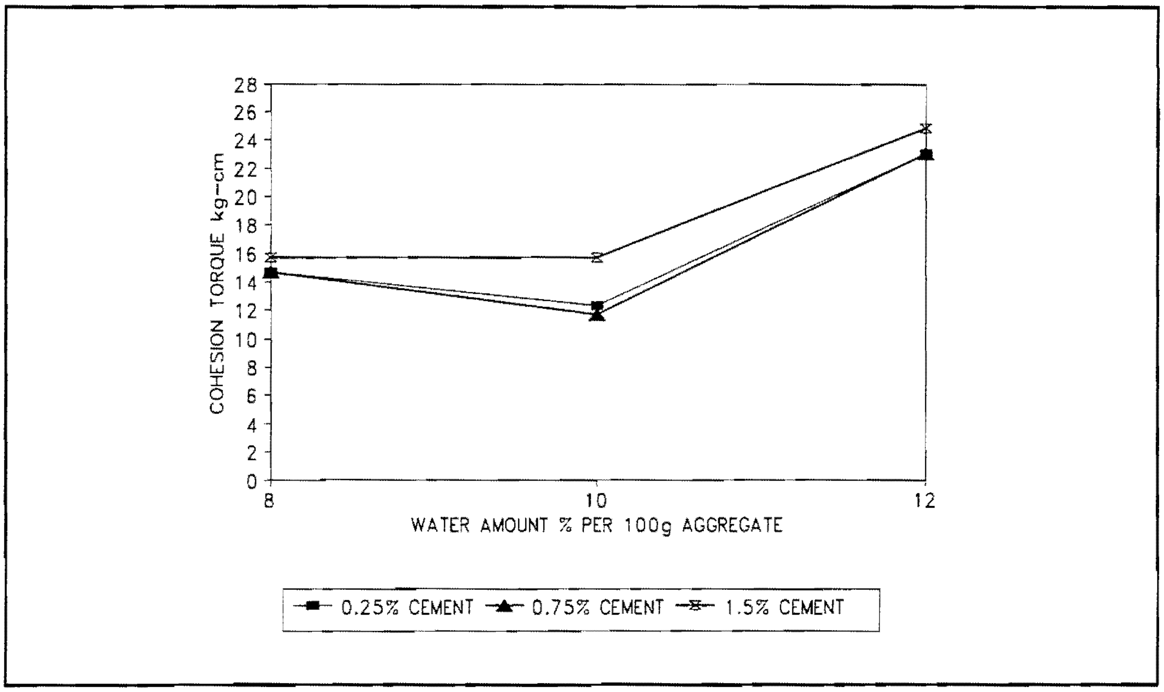

Figure 38. 60-minute wet cohesion torque values against water content with 0.05 percent additive addition

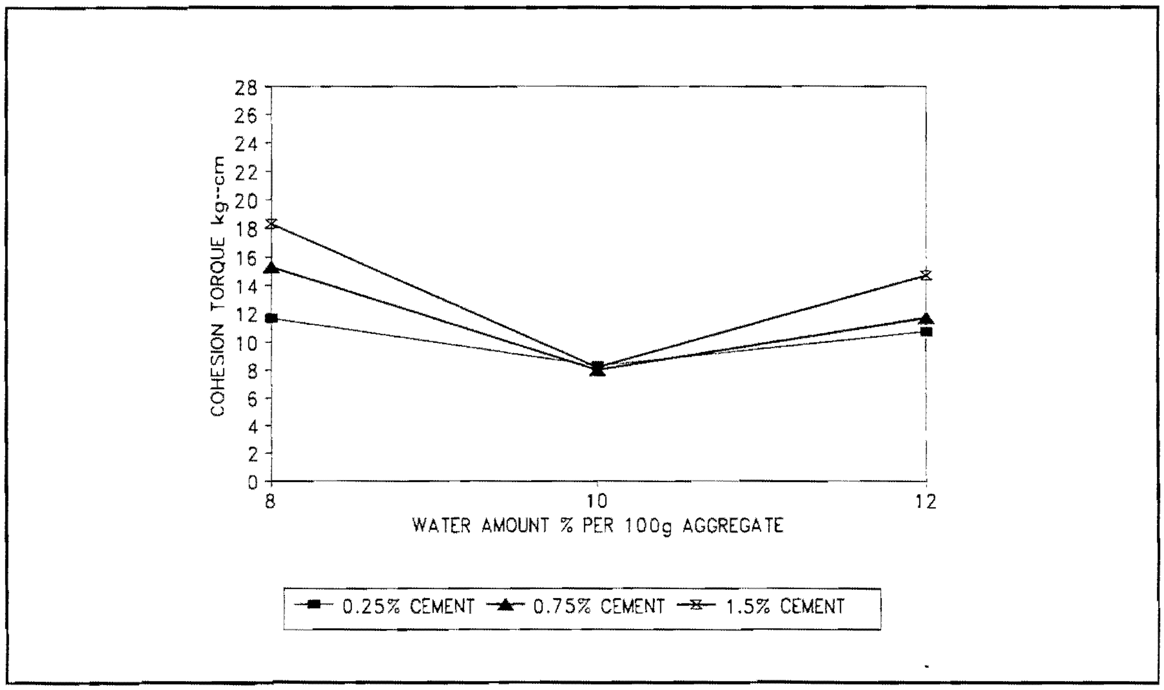

Figure 39. 60-minute wet cohesion torque values against water content with 0.1 percent additive addition

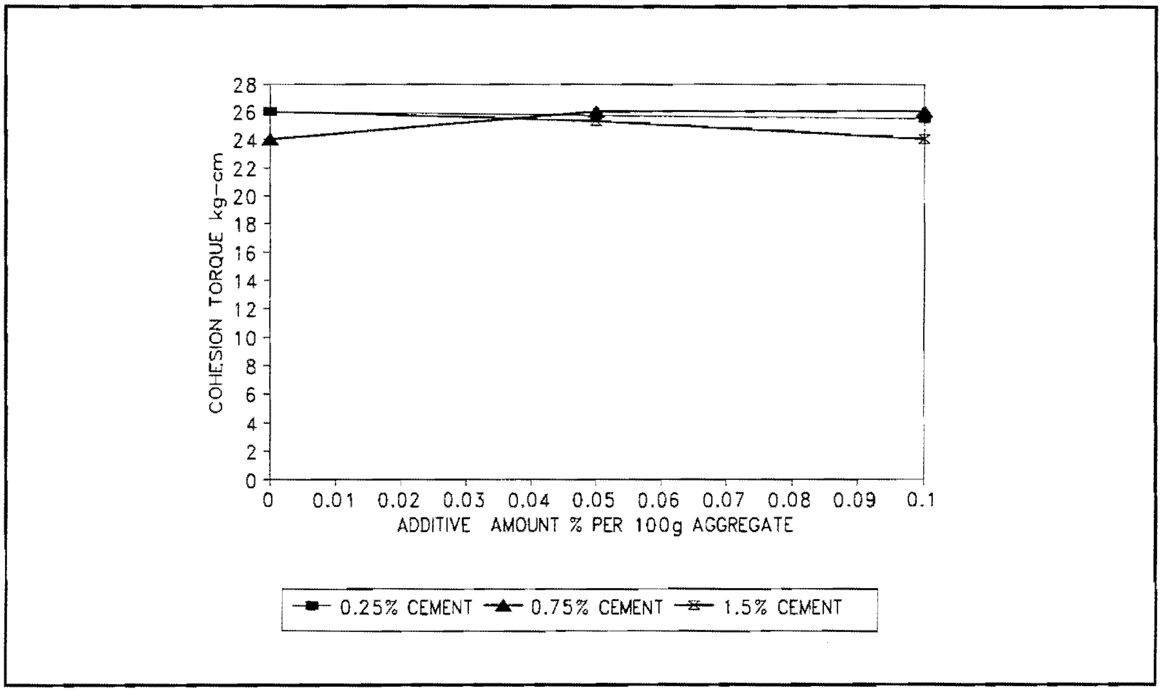

Figure 40. 24-hour cured cohesion torque values against additive amount with 8 percent water

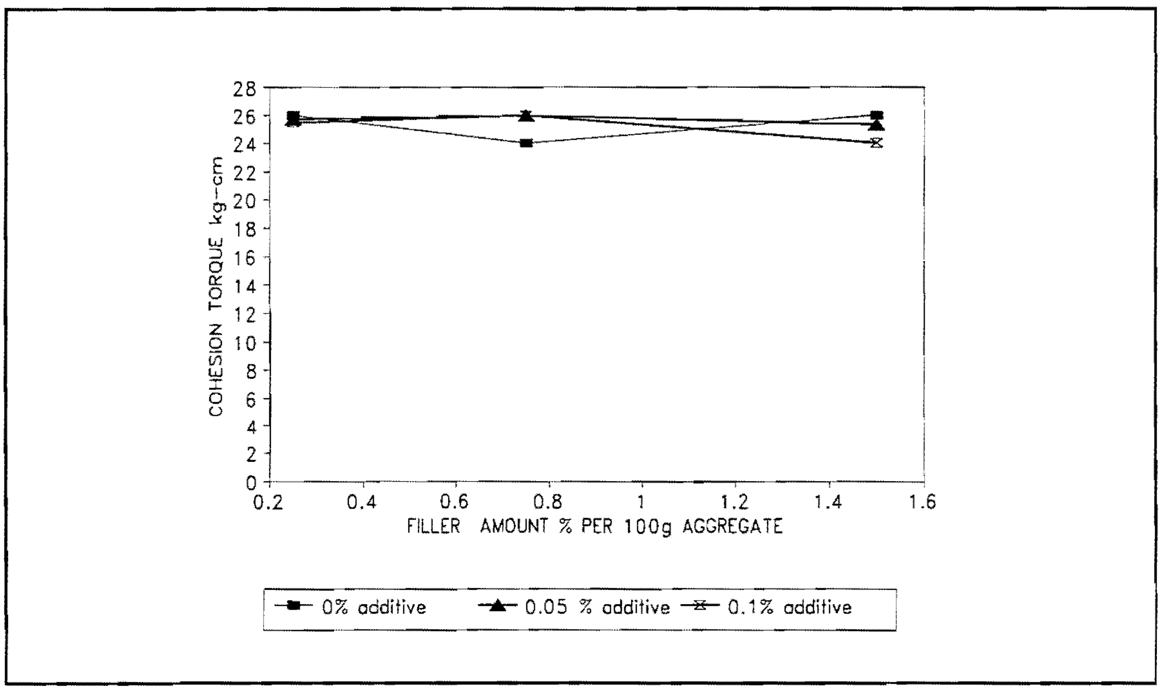

Figure 41. 24-hour cured cohesion torque values against mineral filler with 8 percent water

Figure 41 shows that when there is very little water in the system, cohesion values realized after 24 hours of curing do not appear to be affected significantly by the amounts of mineral filler or additive used in the mixture formulation.

Figures 42 and 43 are plots of cohesion values after 24 hours curing versus additive amount and mineral filler, respectively, for mixtures with a moderate water content of 10 percent. Figure 42 shows that, at moderate water contents, cohesion values are relatively stable. It decreases only for mixtures with more than 0.05 percent additive and less than the high mineral filler content of 1.5 percent. Comparing Figure 42 to Figure 40 shows that mixtures with low mineral filler contents and moderate water contents yield lower cohesion values after 24 hours curing.

Figure 43 shows that mixtures with a higher amount of filler converge to nearly the same cohesion after 24 hours of curing for all additive amounts. Comparing Figure 43 to Figure 41 shows that mixtures with high additive amounts and moderate amounts of water do not develop as much cohesion as mixtures made with less water.

Figures 44 and 45 are plots of cohesion values after 24 hours curing versus additive amount and mineral filler, respectively, for mixtures with a high water content of 12 percent. Figure 44 shows that at high water content, larger cohesion values can be achieved with high mineral filler contents of 1.5 percent for all additive contents. With mineral filler contents of 0.75 percent, mixtures lose some cohesion as additive is increased to high levels of 0.1 percent. There is a decrease in cohesion for systems without additive and 0.75 percent cement.

Figure 45 shows that there is an increase in cohesion as mineral filler amount is increased for all additive amounts, when mixtures have high water contents. For acceptable cohesion values to occur when 0.05 percent additive is used, mineral filler should be greater than 0.75 percent.

Figure 46 is a graph of cohesion values versus water content with zero percent additive. This graph indicates that for mixtures without any additive, high water contents at all mineral filler contents yield unacceptable values.

Figure 47 is a graph of cohesion values versus water content with 0.05 percent additive addition. Mixtures with low mineral filler amounts lose cohesion as water is increased.

Figure 48 is a graph of cohesion values versus water content with 0.1 percent additive addition. The trend suggested by this figure shows that when high amounts of additive and water are used in the mixture, to achieve the greatest amounts of cohesion, high values of mineral filler should be used. This is important to note, because certain field environmental conditions necessitate the use of higher quantities of additive, an example being construction in temperatures over 100°F. At such temperatures, the

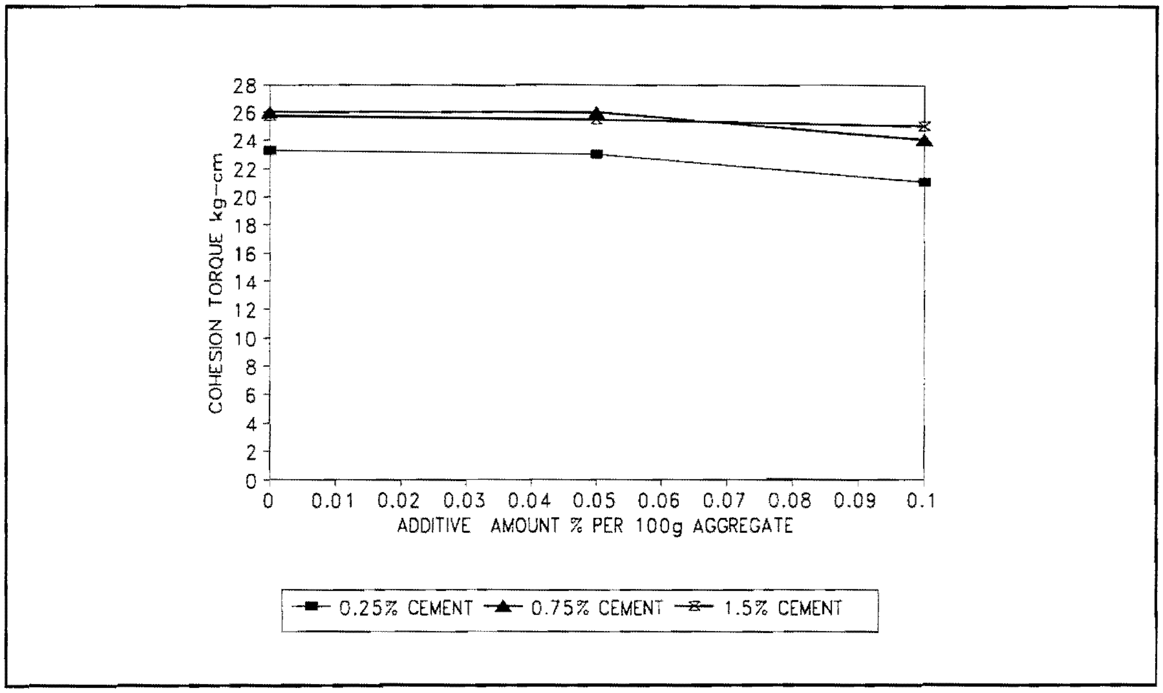

Figure 42. 24-hour cured cohesion torque values against additive amount with 10 percent water

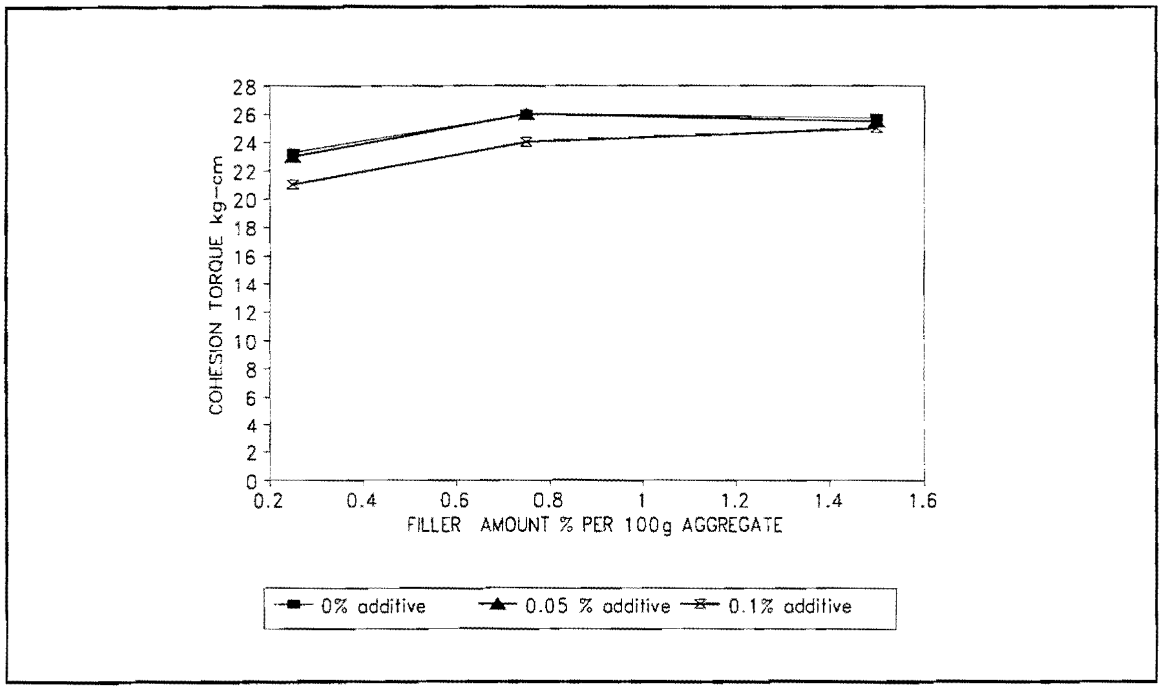

Figure 43. 24-hour cohesion torque values against mineral filler with 10 percent water

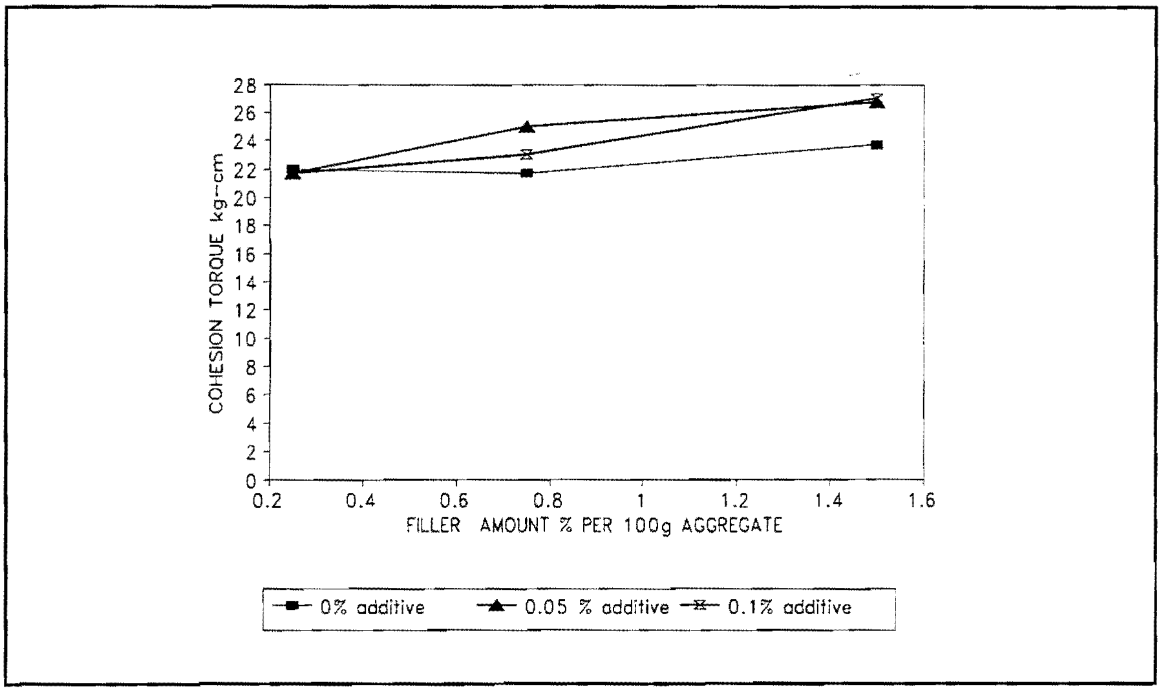

Figure 44. 24-hour cured cohesion torque values against mineral filler with 12 percent water

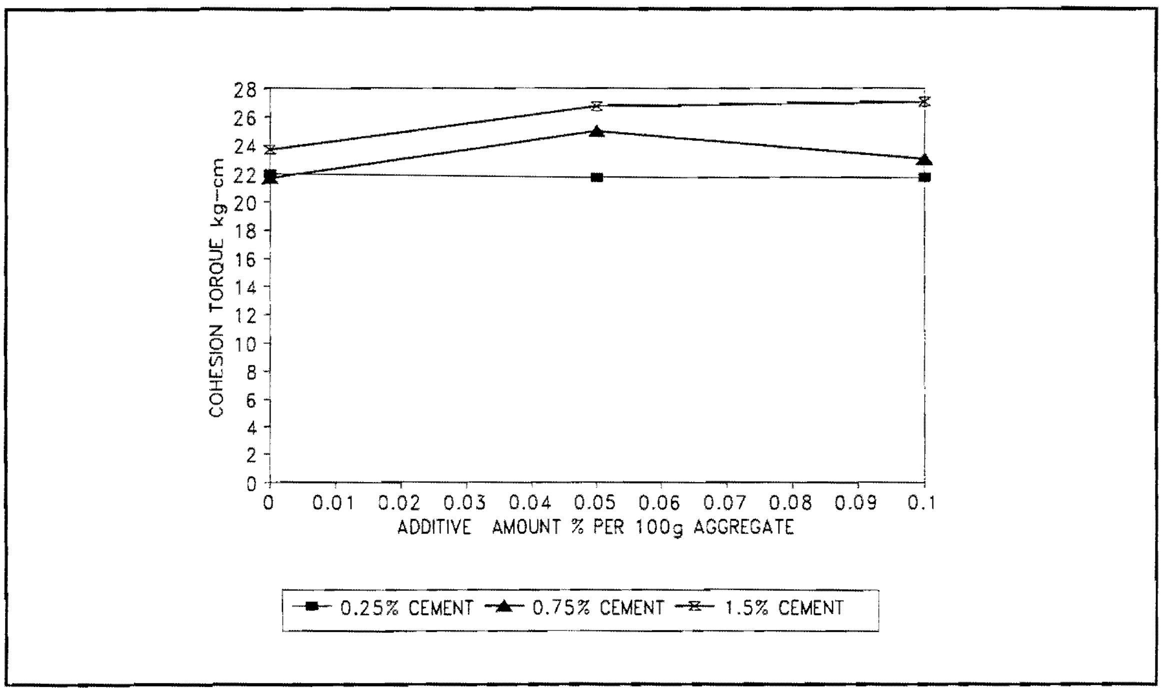

Figure 45. 24-hours cured cohesion torque values against additive amount with 12 percent water

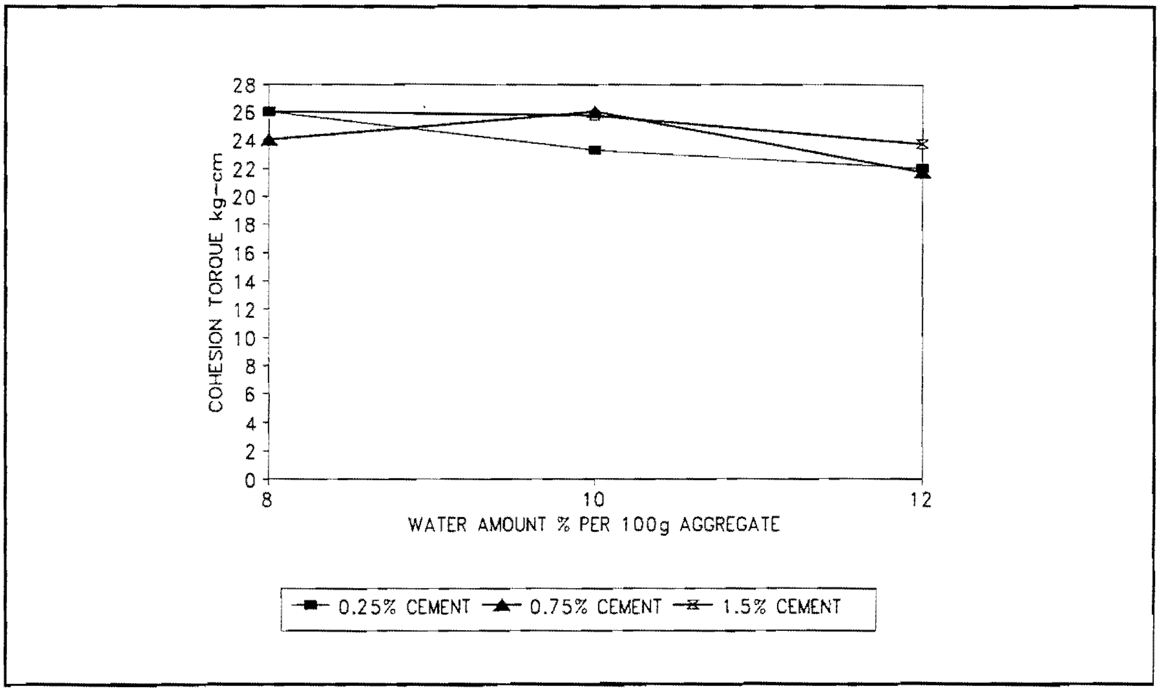

Figure 46. 24-hour cured cohesion torque values against water content with 0.0 percent additive addition.

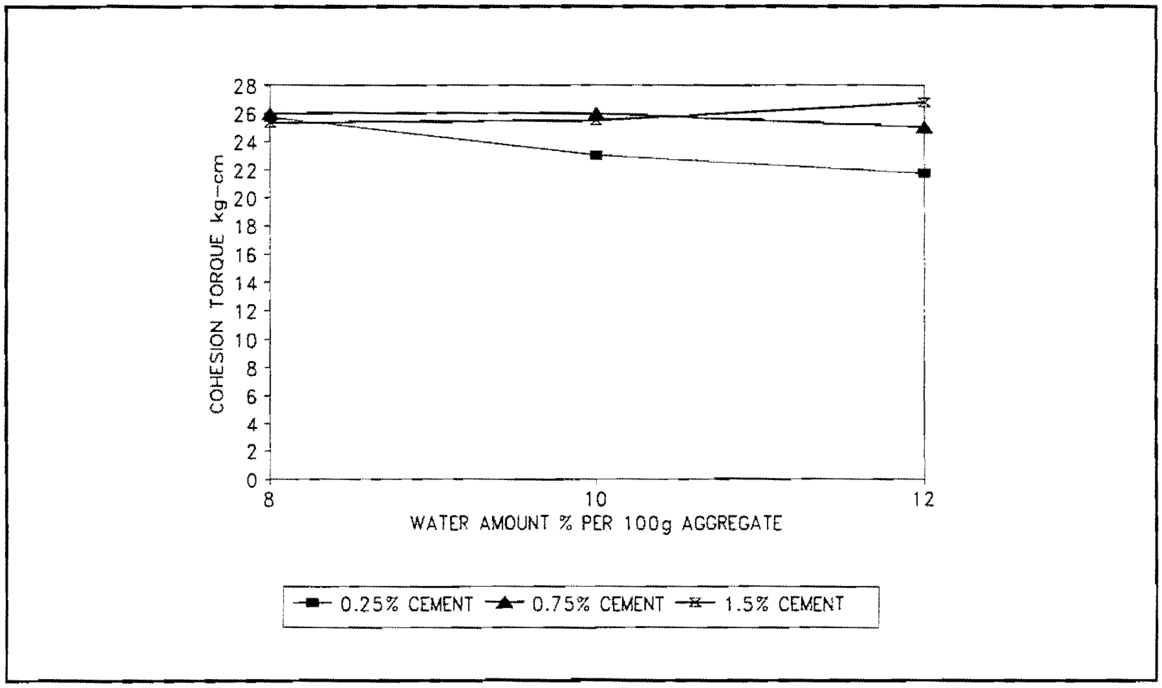

Figure 47. 24-hour cured cohesion torque values against water content with 0.05 percent additive addition

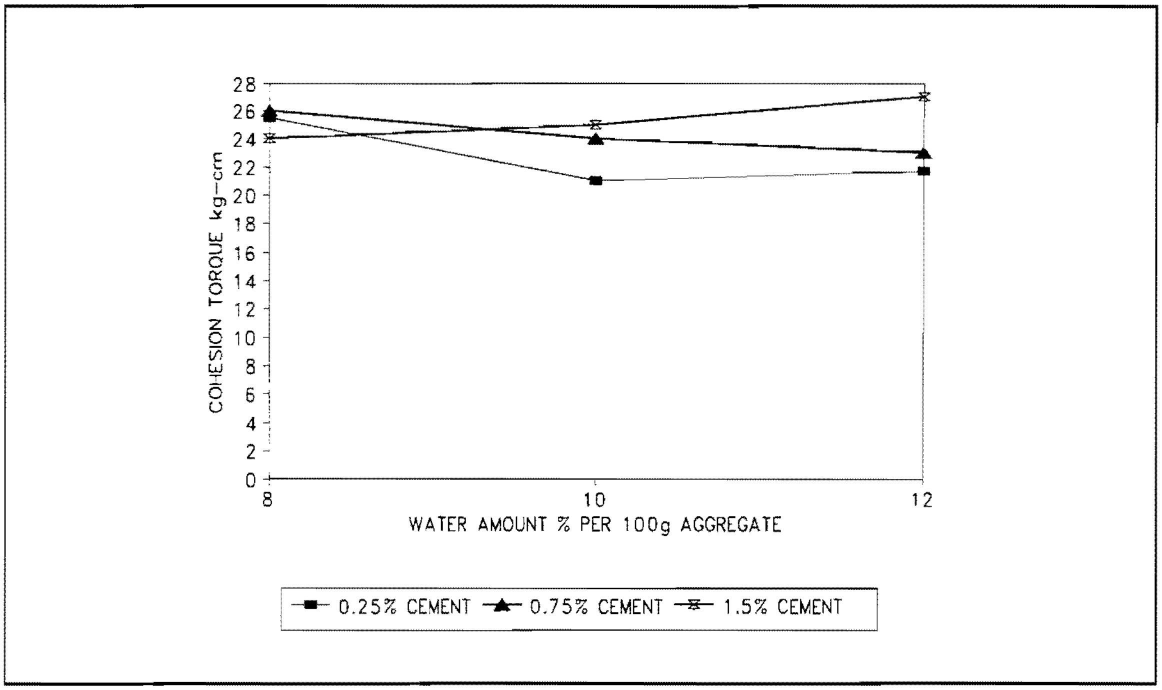

Figure 48. 24-hour cured cohesion torque values against water contents with 0.1 percent additive

mixture sets up fast, but the set time is extended by using a high concentration of additive, e.g., 0.1 percent. Under such circumstances, it is advisable to use a high amount of mineral filler, such as 1.5 percent, to achieve high 24-hour cured cohesion values.

Overall, mineral filler seems to have a little effect on the results of the 24-hour cured cohesion values. Water and additive seem to have little effect.

Loaded Wheel Test Data

Figure 49 is a plot of raw data for loaded wheel test sand adhesion values versus additive amount with 8 percent water. At low water contents, all the mixtures have almost the same sand adhesion values. The amount of additive present in the mixture does have a slight effect on the sand adhered at low water contents. The spread between adhered sand values is considerably narrowed as additive amounts are increased.

Figure 50 is a plot of raw data for loaded wheel test sand adhesion values against mineral filler. This graph indicates that there is no substantial lowering of sand adhesion as mineral filler is increased for systems with low amounts of water.

Figures 51 and 52 are the plots of raw data for loaded wheel test sand adhesion values against additive amounts and mineral filler, respectively, with 10 percent water. When the mixtures contain moderate amounts of additive and mineral filler there is a sharp increase in sand adhered.

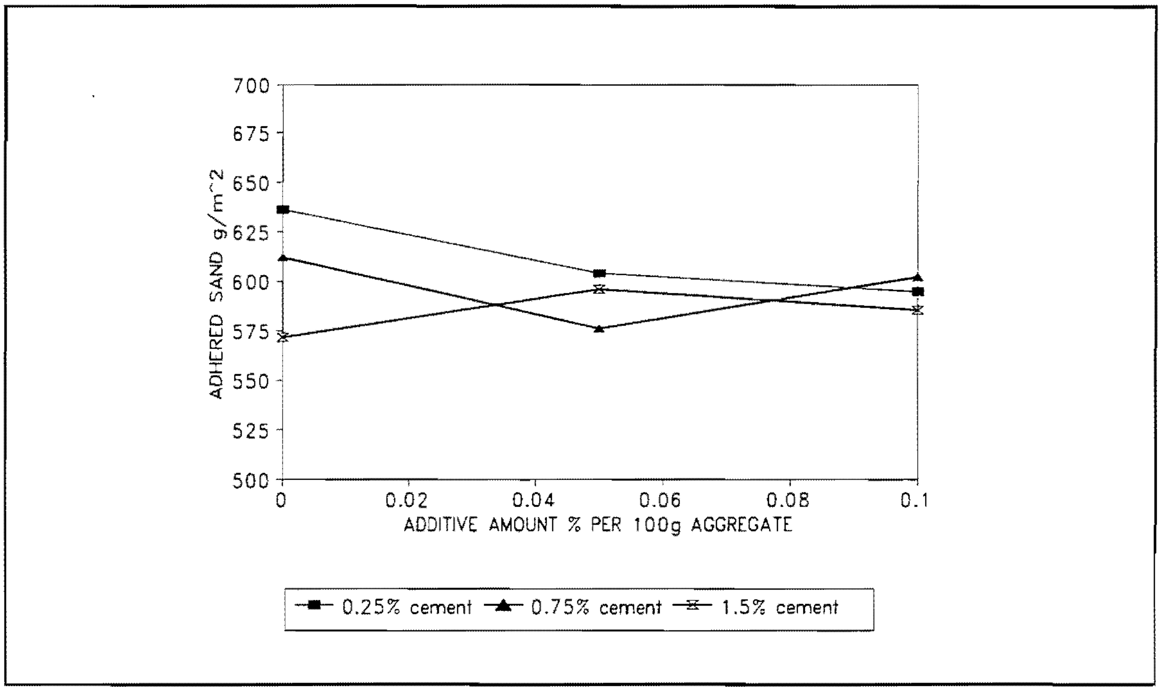

Figure 49. Loaded wheel test sand adhesion values against additive amounts with 8 percent water

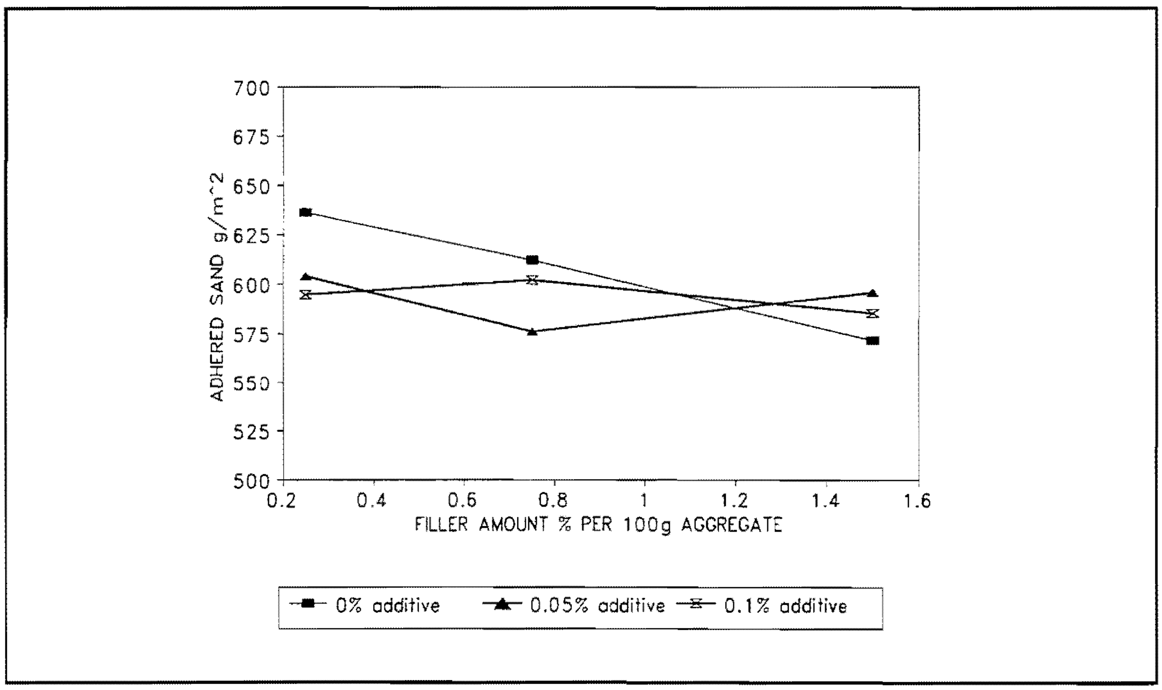

Figure 50. Loaded wheel test sand adhesion values against mineral filler with 8 percent water

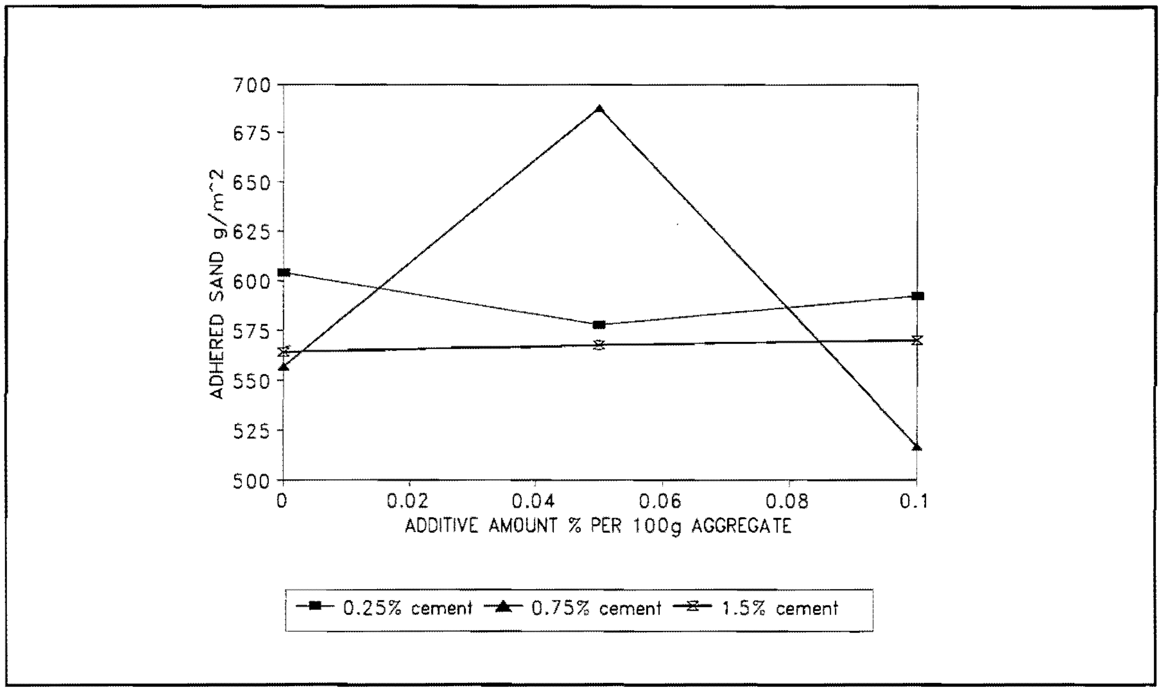

Figure 51. Loaded wheel test sand adhesion values against additive amounts with 10 percent water

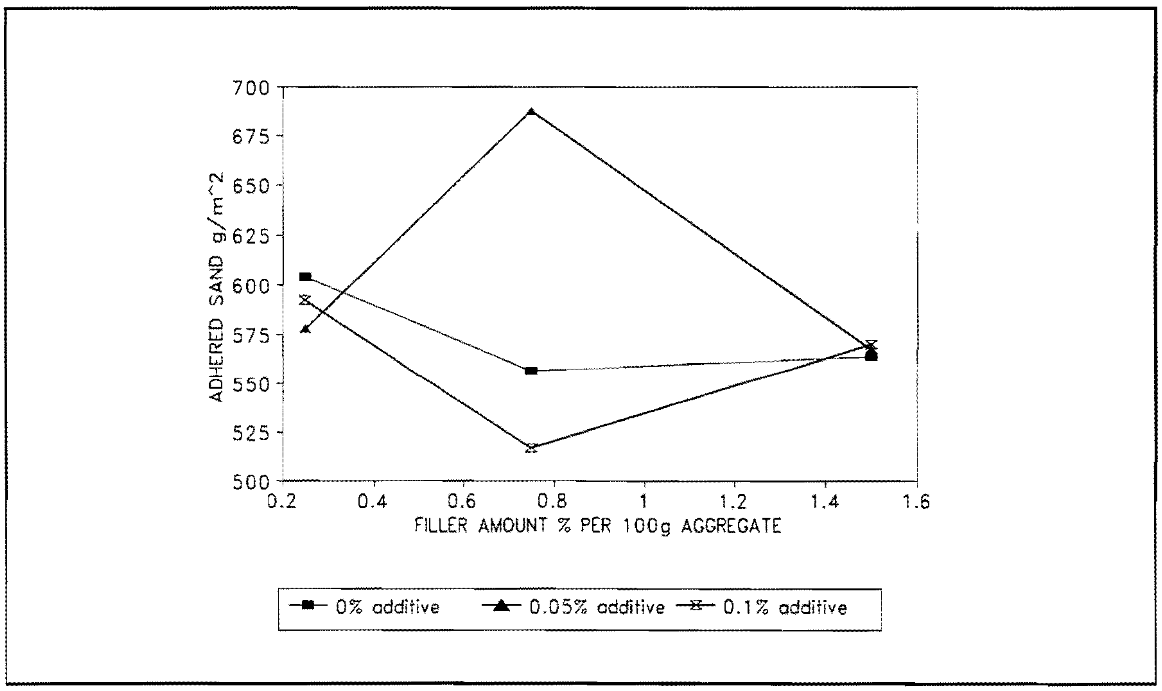

Figure 52. Loaded wheel test sand adhesion values against mineral filler with 10 percent water

Figures 53 and 54 are the plots of raw data for loaded wheel test sand adhesion values against additive amounts and mineral filler, respectively, with 12 percent water. As the water in the systems is increased, the sharp increase formed by mixtures with moderate additive and mineral filler hardly decreases.

Figures 55, 56 and 57 show loaded wheel test sand adhesion values versus water content with 0, 0.5 and 0.1 percent additive. The trend depicted by the graphs are that apart from the curious phenomenon displayed by mixtures containing 0.75 percent mineral filler with additive addition, the sand adhesion results obtained for all other systems are extremely similar and do not significantly distinguish between variations in water or mineral filler.

Water content seems to have a big effect of the result of the loaded wheel test results. However, the results are extremely variable.

6-Day Soak Wet Track Abrasion Test Data

Figures 58 and 59 show 6-day wet track abrasion values versus additive amounts and mineral filler amounts, respectively, with 8 percent water. The high values for abrasion loss and erratic pattern suggest that mixtures with low water contents are not stable. Even with high amounts of additive and low filler content, abrasion loss experienced is barely below the acceptable values of 807 g/m^2 (75 g/ft^2).

Figures 60 and 61 are graphs that show 6-day wet track abrasion values versus additive amounts and mineral filler amounts, respectively, both with 10 percent water content. A more uniform pattern of abrasion loss is achieved and the values for abrasion loss are significantly lower than that of mixtures made with 8 percent water.

Figures 62 and 63 are graphs that show 6-day wet track abrasion values versus additive amounts and mineral filler amounts, respectively, both with 12 percent water content. Abrasion loss was lowest for the sample with no additive, and abrasion loss increased as the amount of additive increased. Figure 62 shows that for systems with additive, abrasion loss increases with additive. Figure 64 illustrates a peak observed with mineral filler addition. It should be noted that 1.5 percent mineral filler has smaller abrasion loss than 0.75 percent mineral filler with 0.25 percent mineral filler showing the least abrasion. With 1.5 percent mineral filler in the formulation an addition of greater than 0.05 percent additive does not significantly increase abrasion loss. The uniform trend depicted in the graphs suggests that high amounts of water are necessary to achieve coherent results when using the wet track abrasion test.

Figures 64, 65 and 66 are graphs of 6-day soak wet track abrasion values against water content with 0, 0.5 and 0.1 percent additive addition, respectively. These show that there is a definite decrease in abrasion loss as water content is increased.

Overall, water content seems to have the greatest effect. It would appear that we need a method to define the best water content at which to conduct the test.

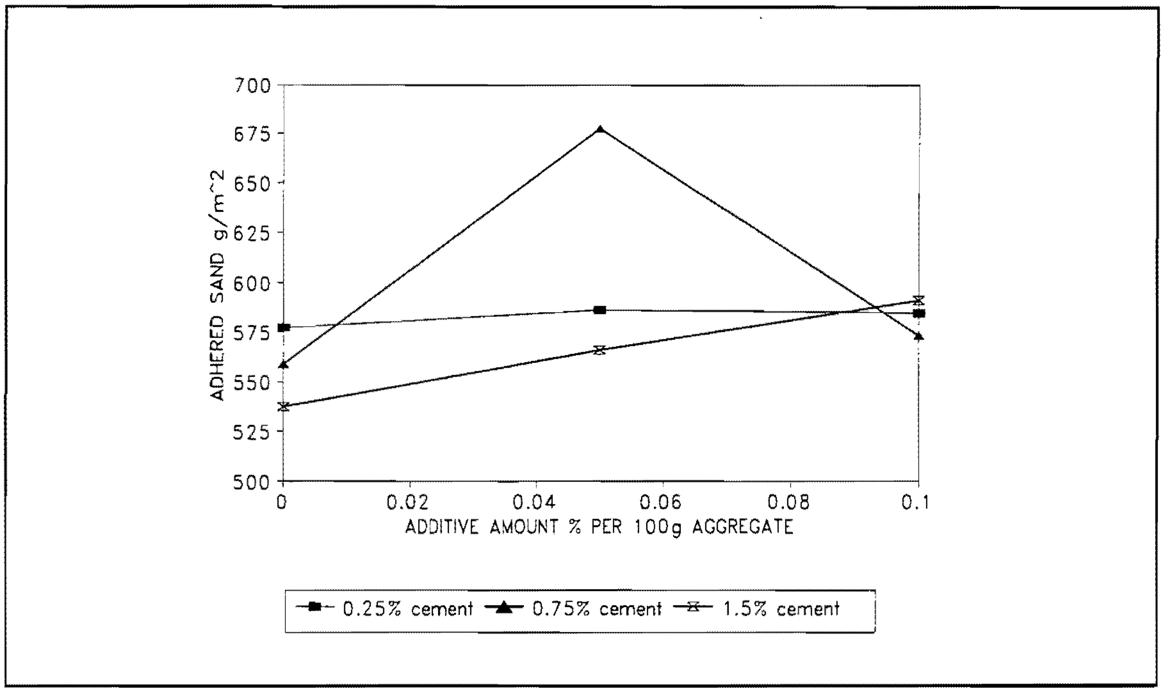

Figure 53. Loaded wheel test sand adhesion values against additive amounts with 12 percent water

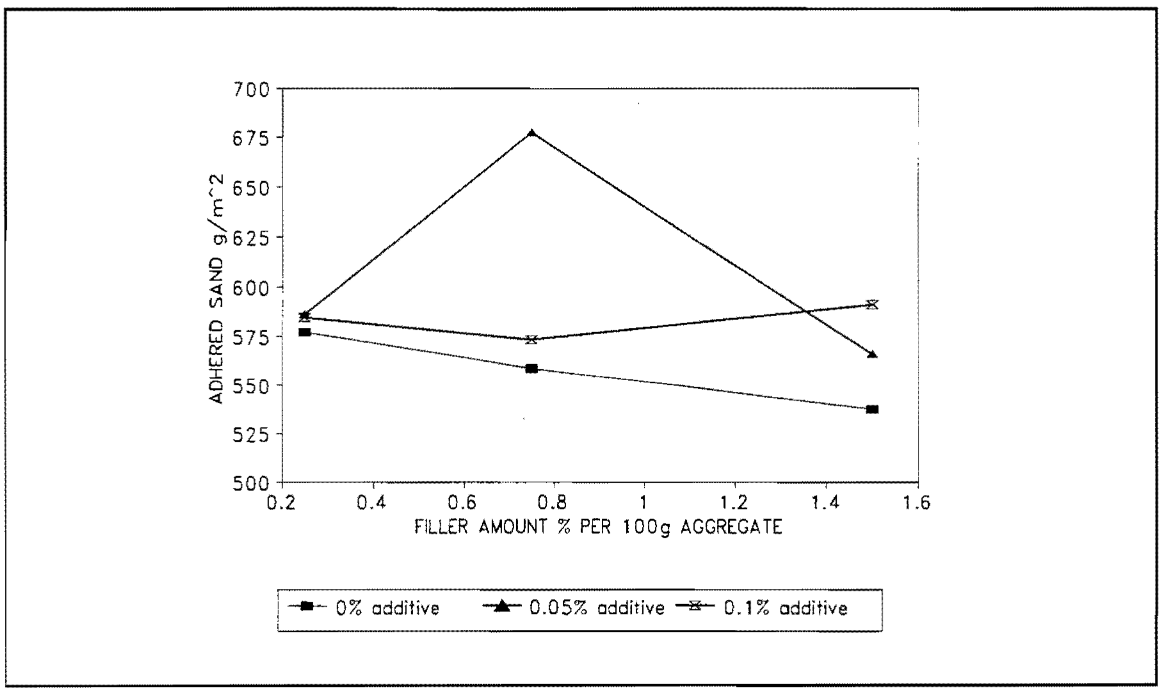

Figure 54. Loaded wheel test sand adhesion values against mineral filler with 12 percent water

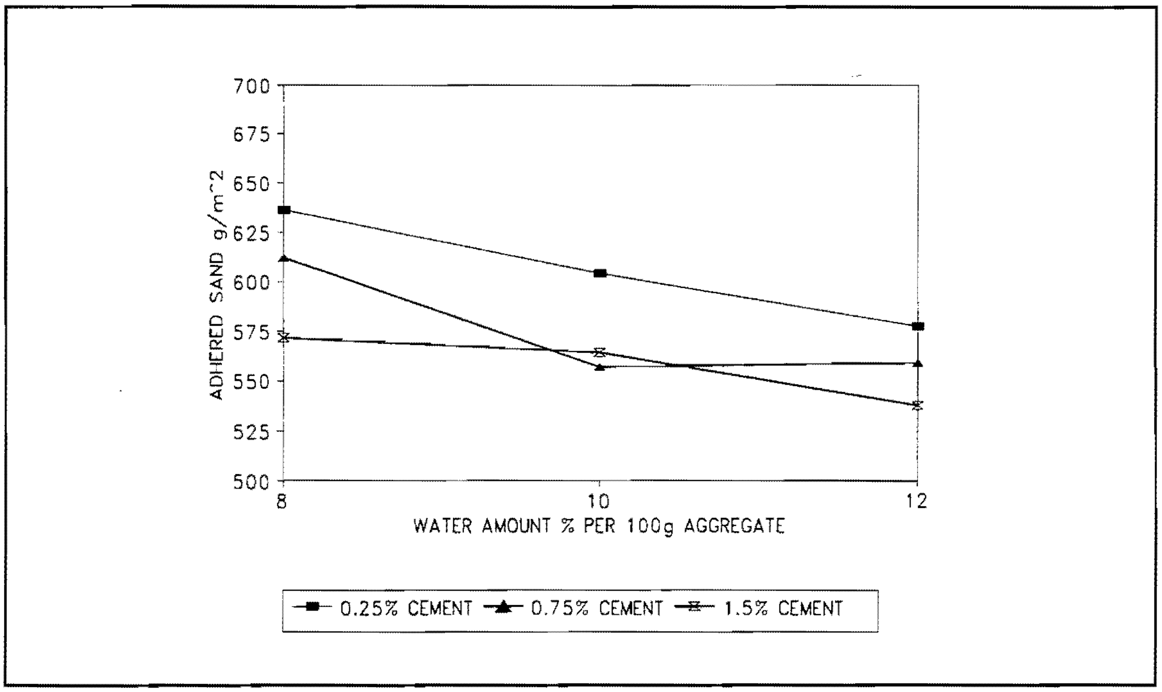

Figure 55. Loaded wheel test sand adhesion values against water content with 0 percent additive addition

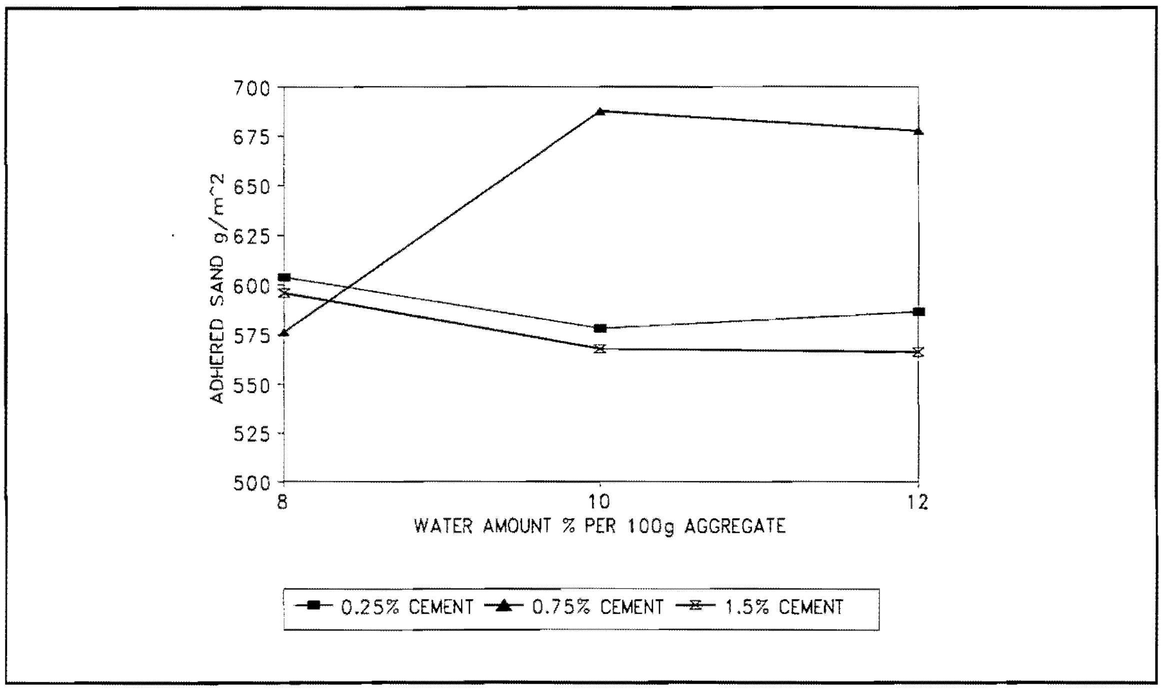

Figure 56. Loaded wheel test sand adhesion values against water content with 0.05 percent additive addition

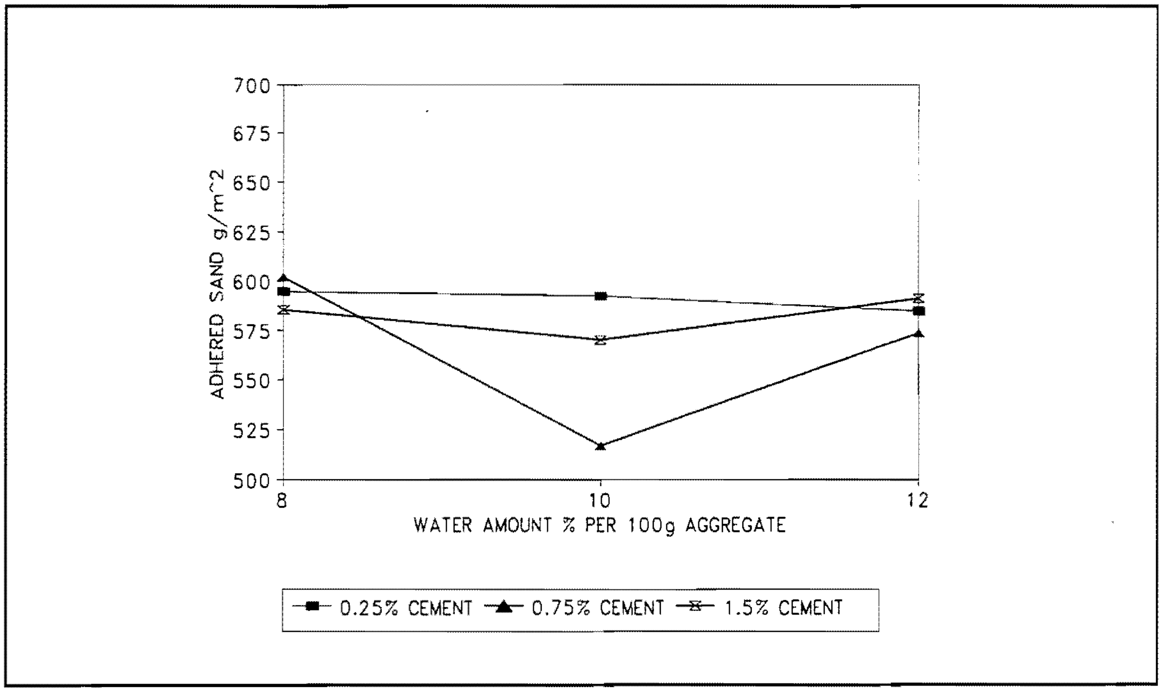

Figure 57. Loaded wheel test sand adhesion values against water content with 0.1 percent additive addition

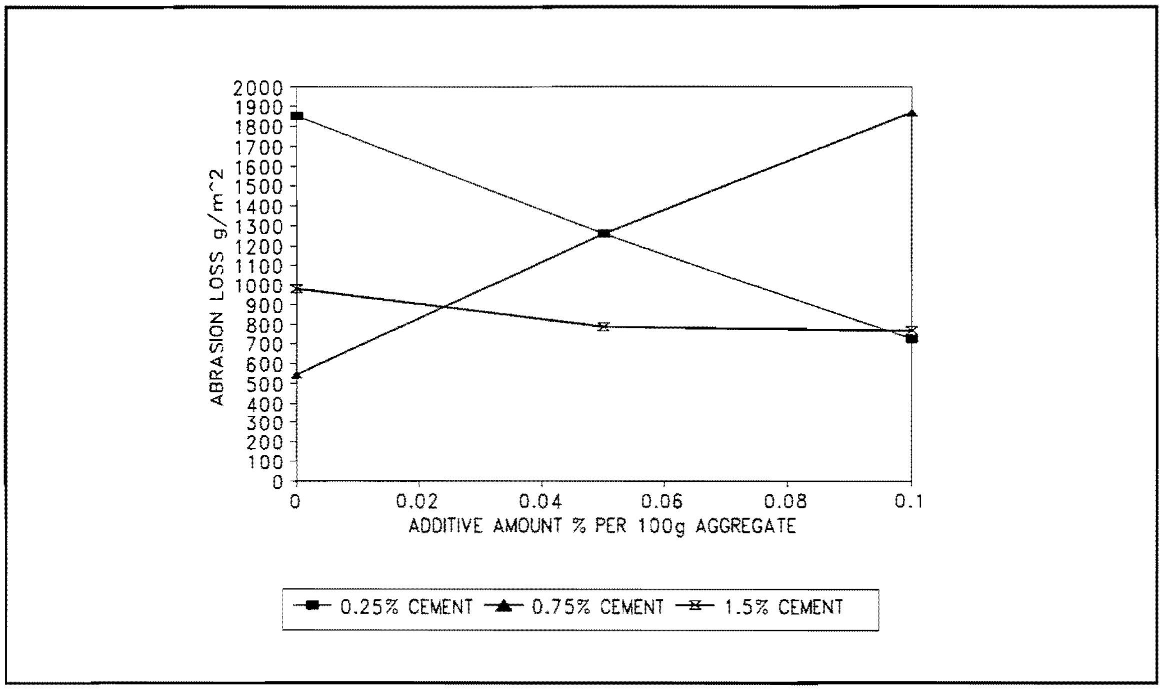

Figure 58. 6-day soak wet track abrasion values against additive amounts with 8 percent water

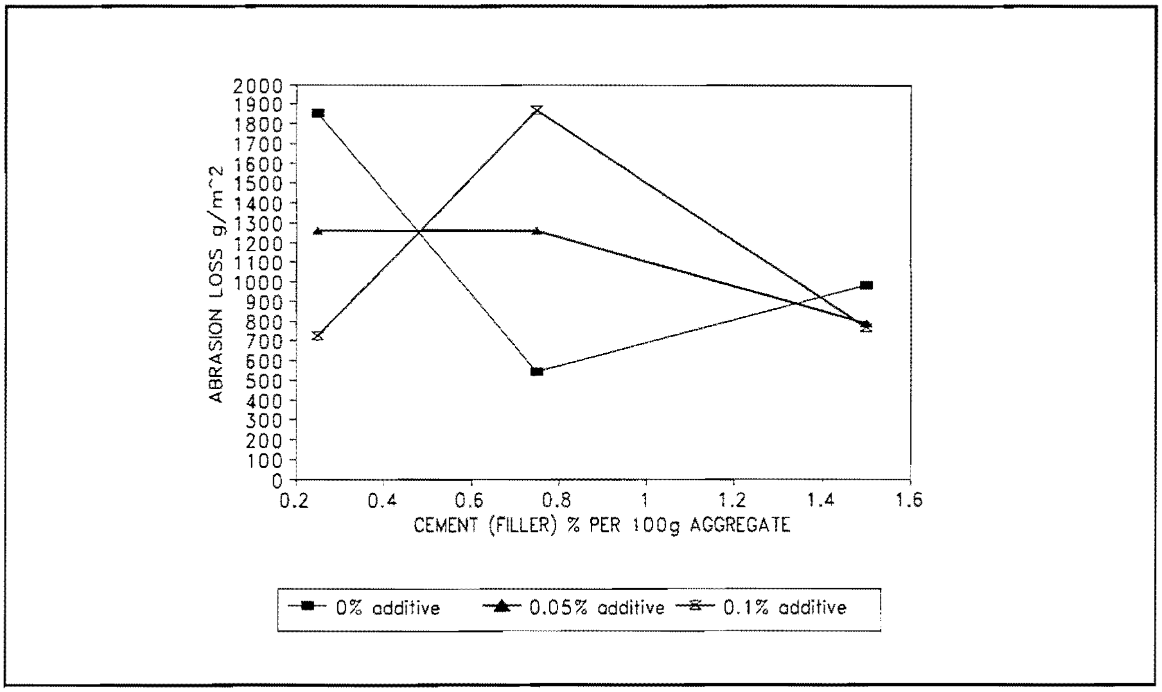

Figure 59. 6-day soak wet track abrasion values against mineral filler with 8 percent water

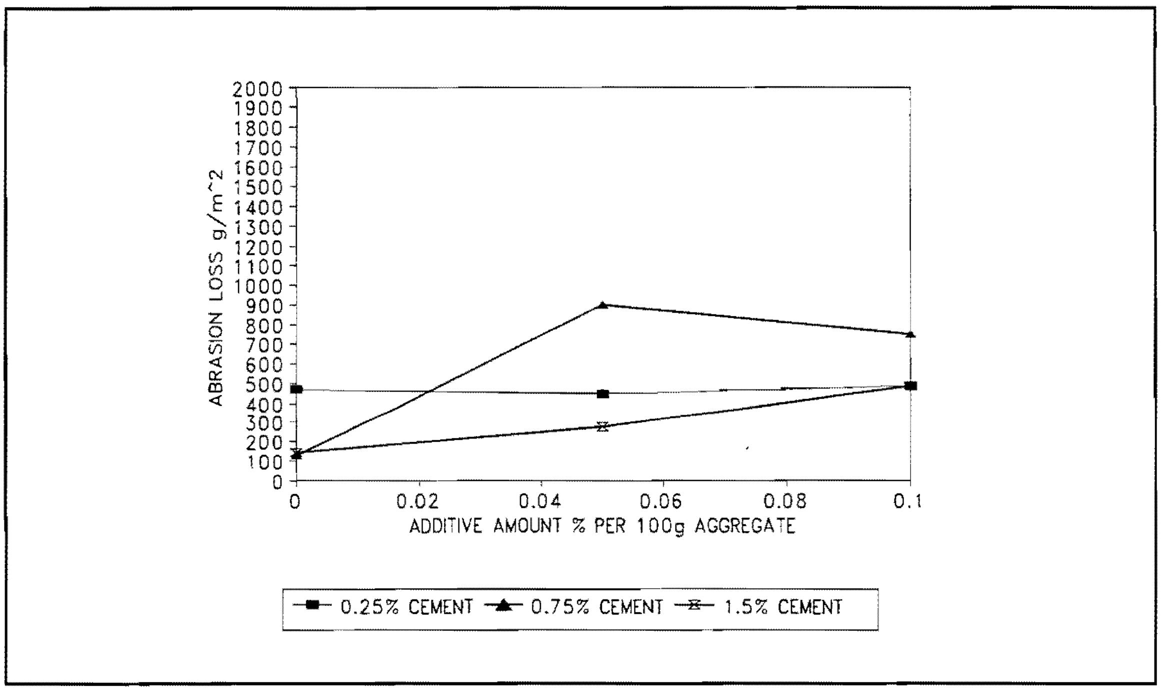

Figure 60. 6-day soak wet track abrasion values against additive amounts with 10 percent water

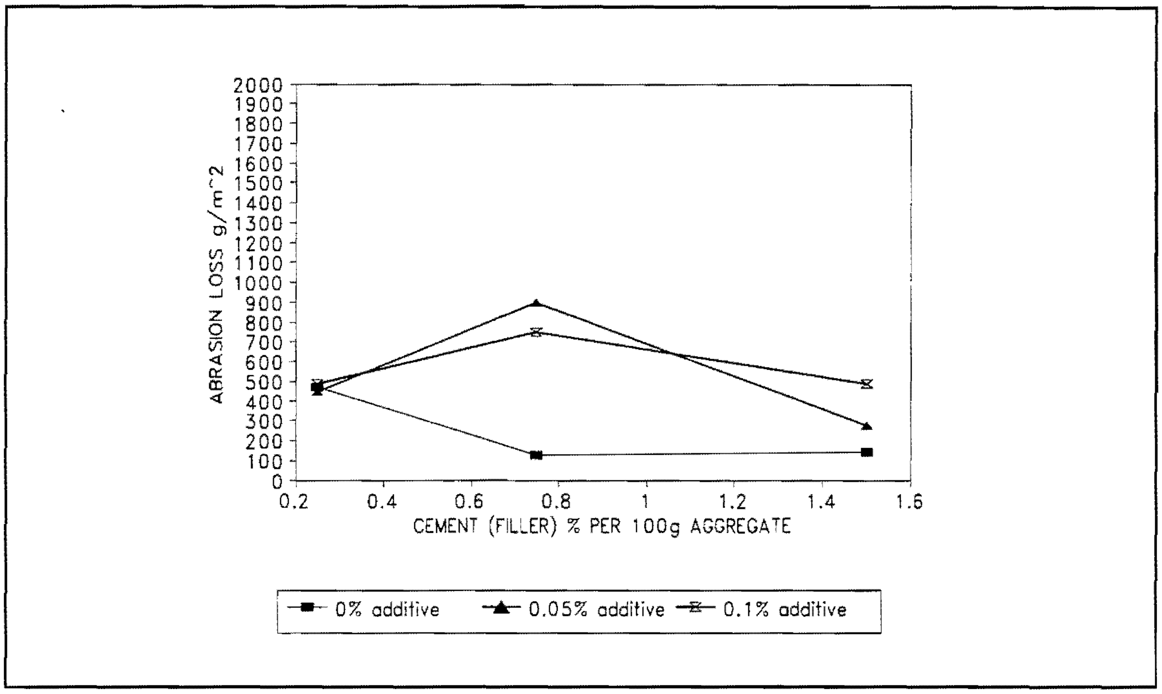

Figure 61. 6-day soak wet track abrasion values against mineral filler with 10 percent water

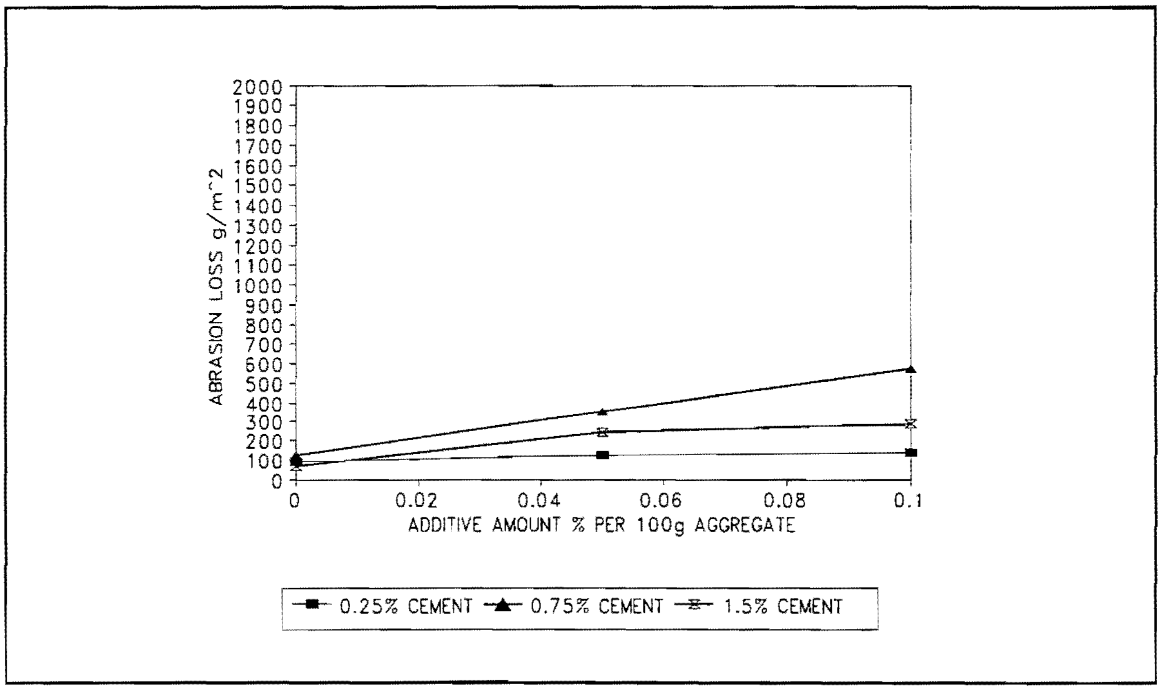

Figure 62. 6-day soak wet track abrasion values against additive amounts with 12 percent water

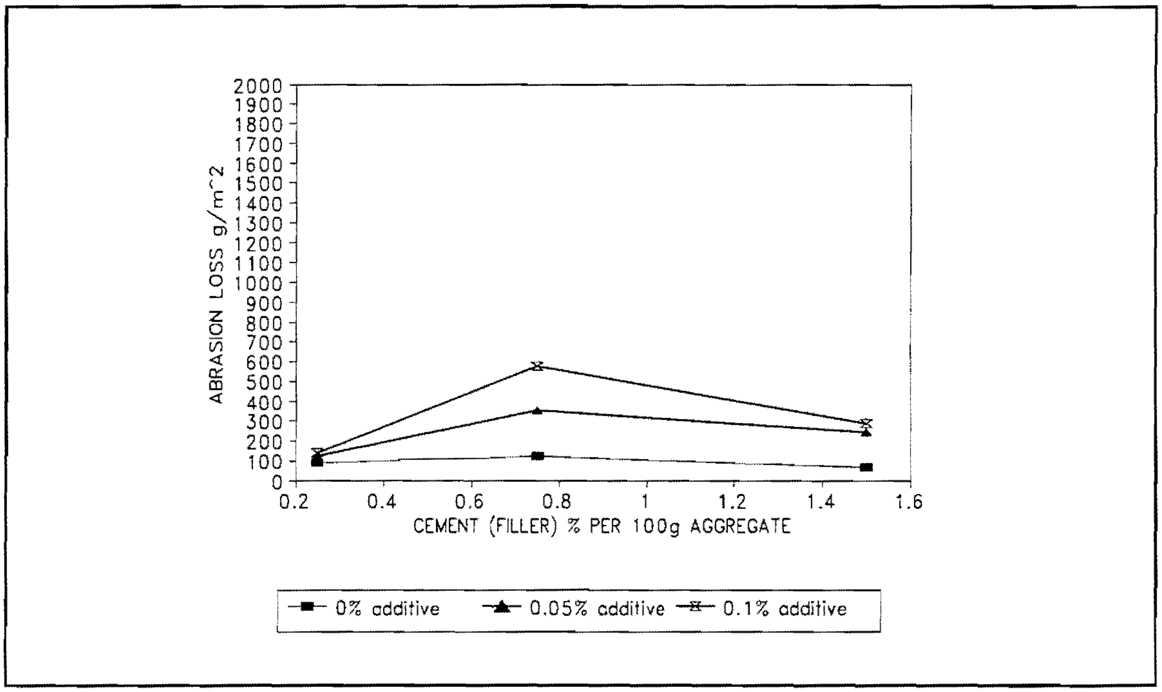

Figure 63. 6-day soak wet track abrasion values against mineral filler with 12 percent water

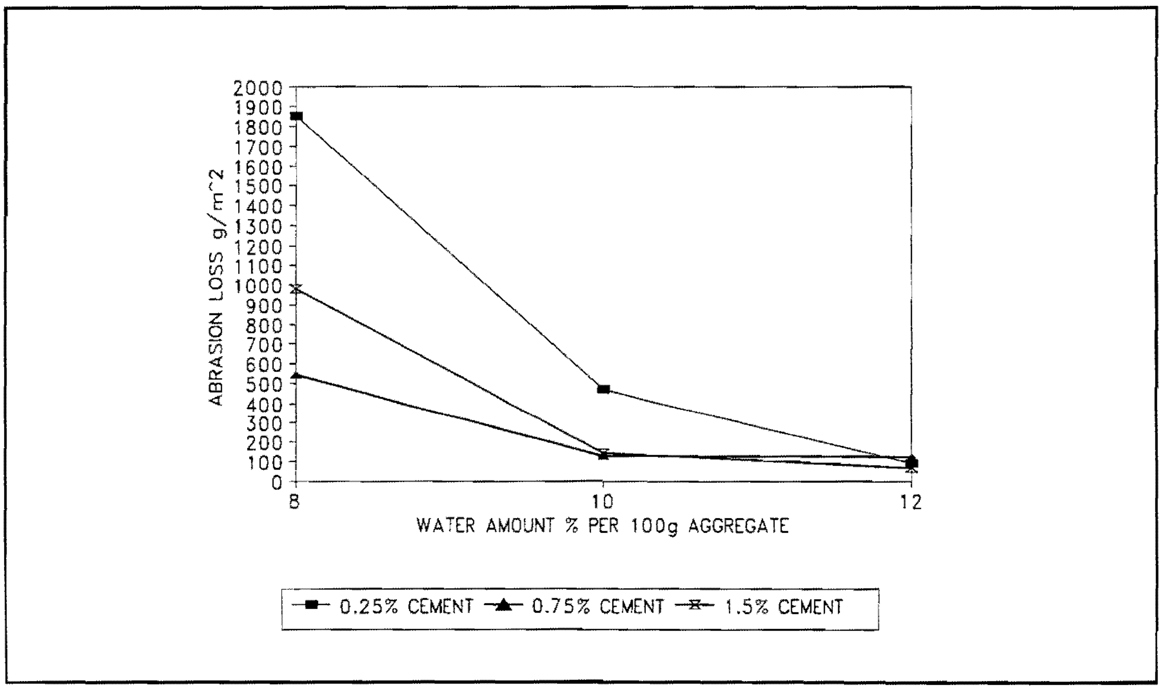

Figure 64. 6-day soak wet track abrasion values against water content with 0 percent additive addition

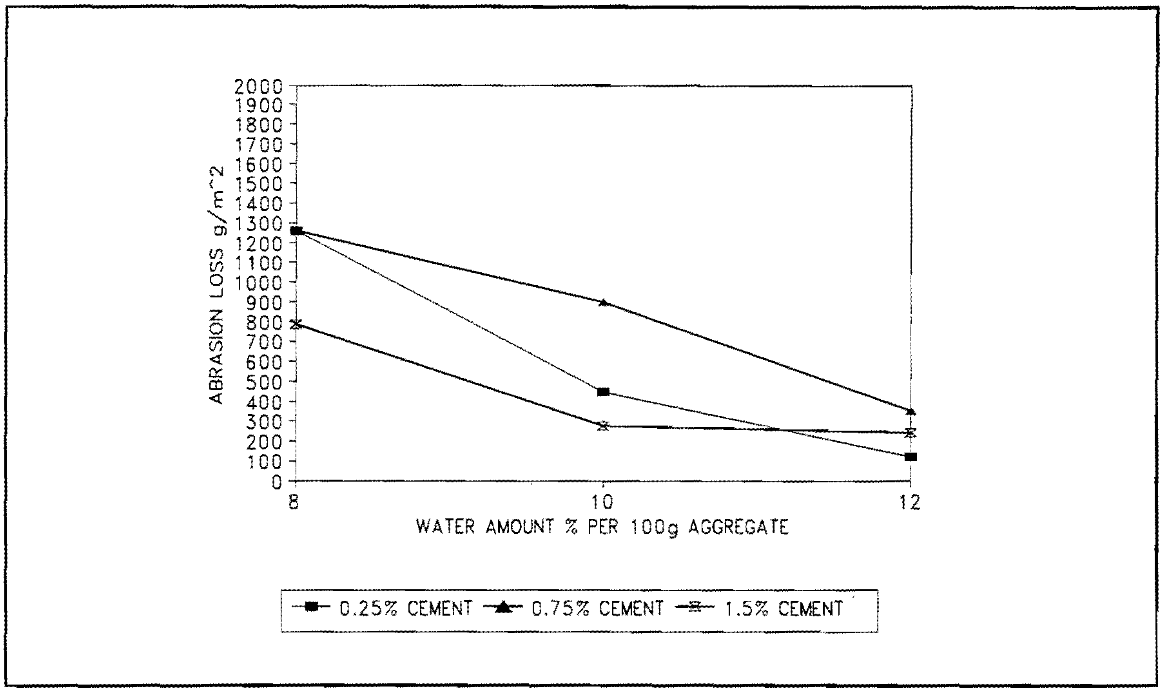

Figure 65. 6-day soak wet track abrasion values against water content with 0.05 percent additive addition

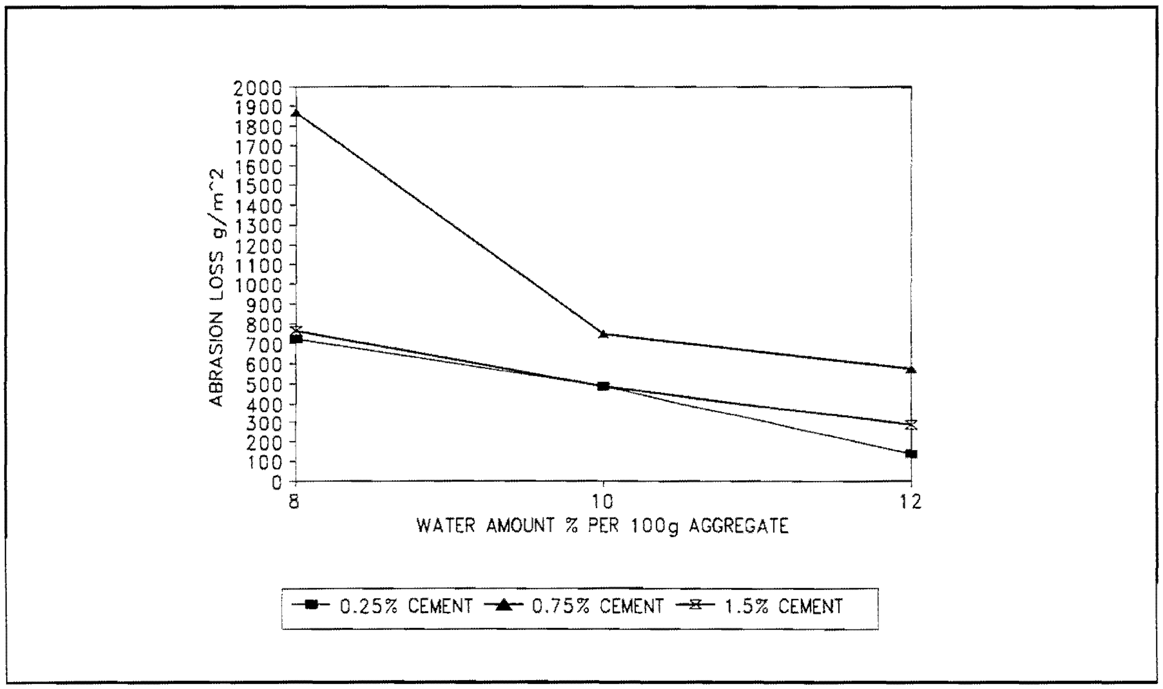

Figure 66. 6-day soak wet track abrasion values against water content with 0.1 percent additive addition

Schulze-Breuer and Ruck Procedures

Figures 67 and 68 are plots of the Schulze-Breuer and Ruck results for abrasion using 0.25, percent 0.75 percent and 1.5 percent mineral filler systems. At 0.75 and 1.5 percent mineral filler, the test does indicate that there is aggregate filler/bitumen compatibility for all amounts of additive addition. For low filler addition of 0.25 percent, the test results indicate that there is inadequate compatibility for systems with no additive and very high additive addition. Figure 68 demonstrates that there is definitely some correlation between mineral filler amount and the compatibility rating. It appears that compatibility is greatly enhanced beyond a specific mineral filler content.

Figures 69 and 70 show plots of the Schulze-Breuer and Ruck procedures for integrity. At low mineral filler content of 0.25 percent and high additive addition of 0.1 percent, no integrity was recorded for the sample.

Overall, the test results from the Schulze-Breuer procedure seem to be sensitive to both the cement and additive contents.

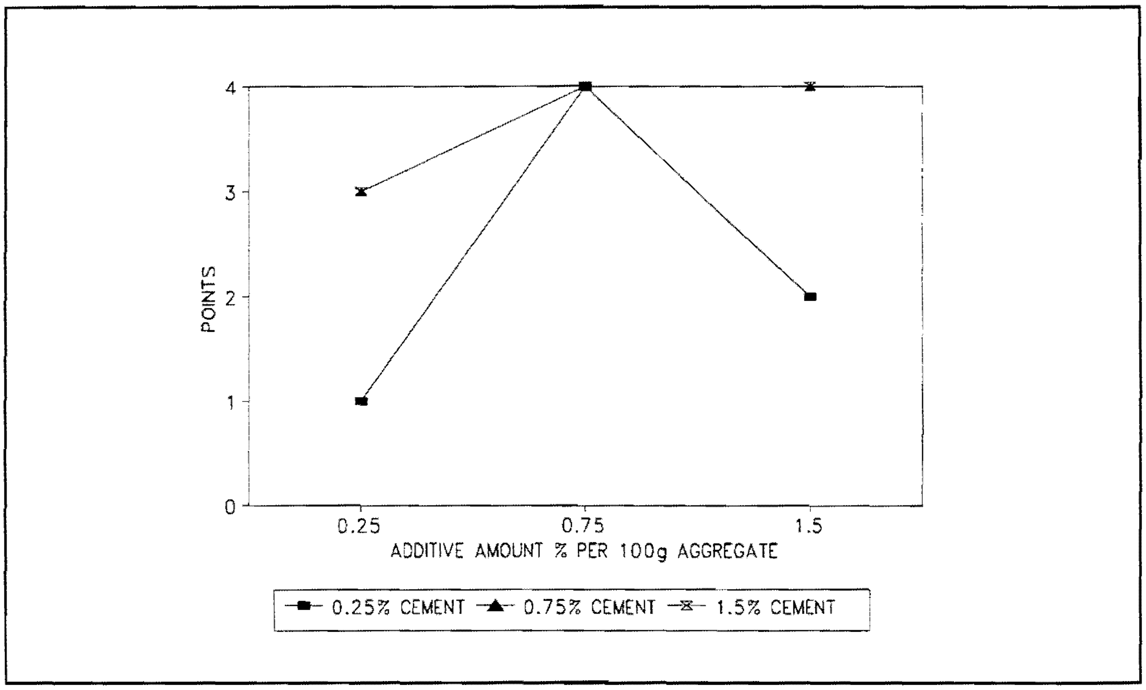

Figure 67. Schulze-Breuer procedure for aggregate mineral filler compatibility, points for abrasion against additive amounts

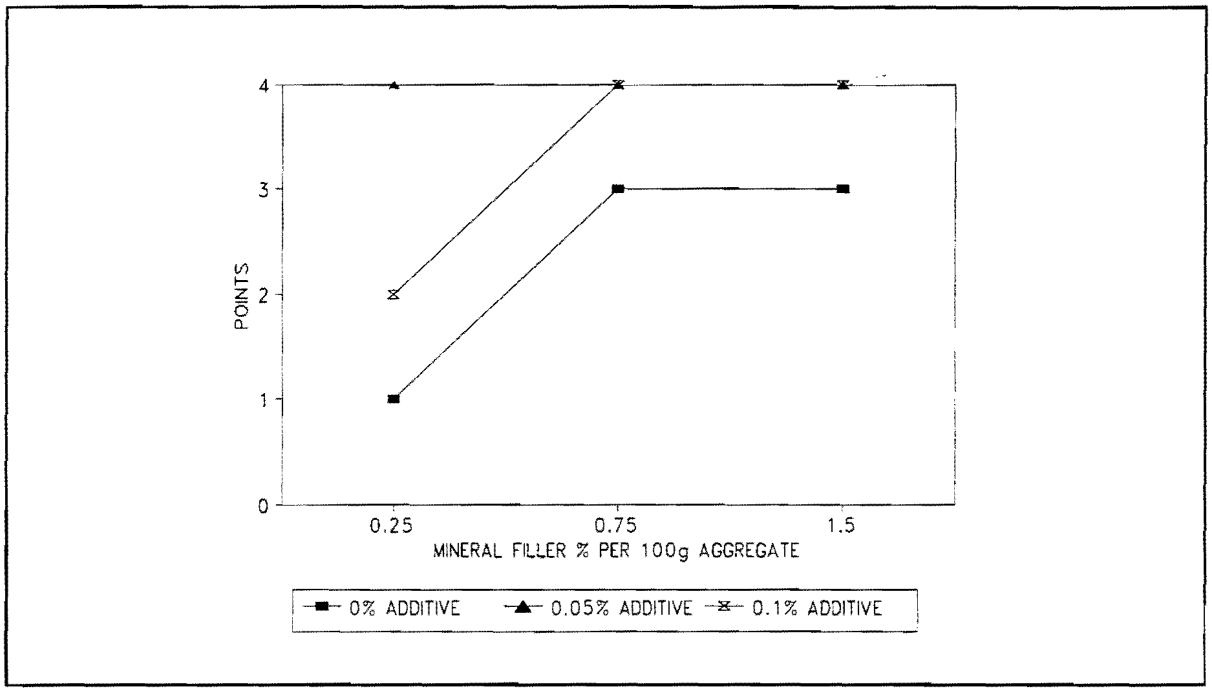

Figure 68. Schulze-Breuer procedure for aggregate mineral filler compatibility, points for abrasion against mineral filler amounts

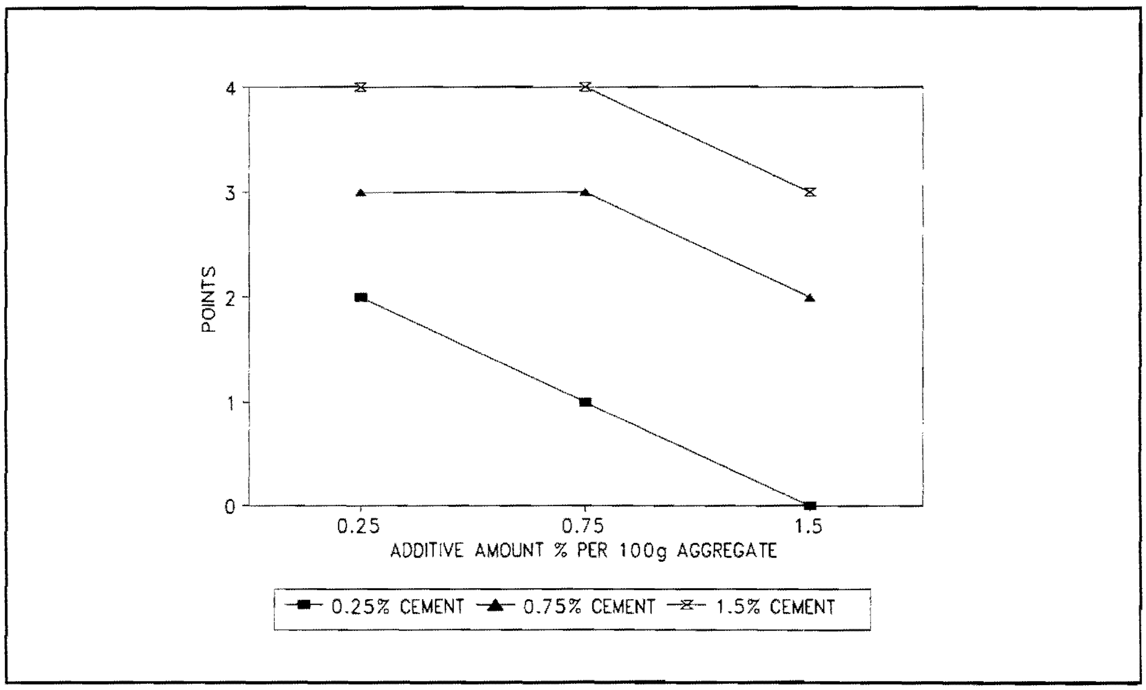

Figure 69. Schulze-Breuer procedure for aggregate mineral filler compatibility, points for integrity against additive amounts

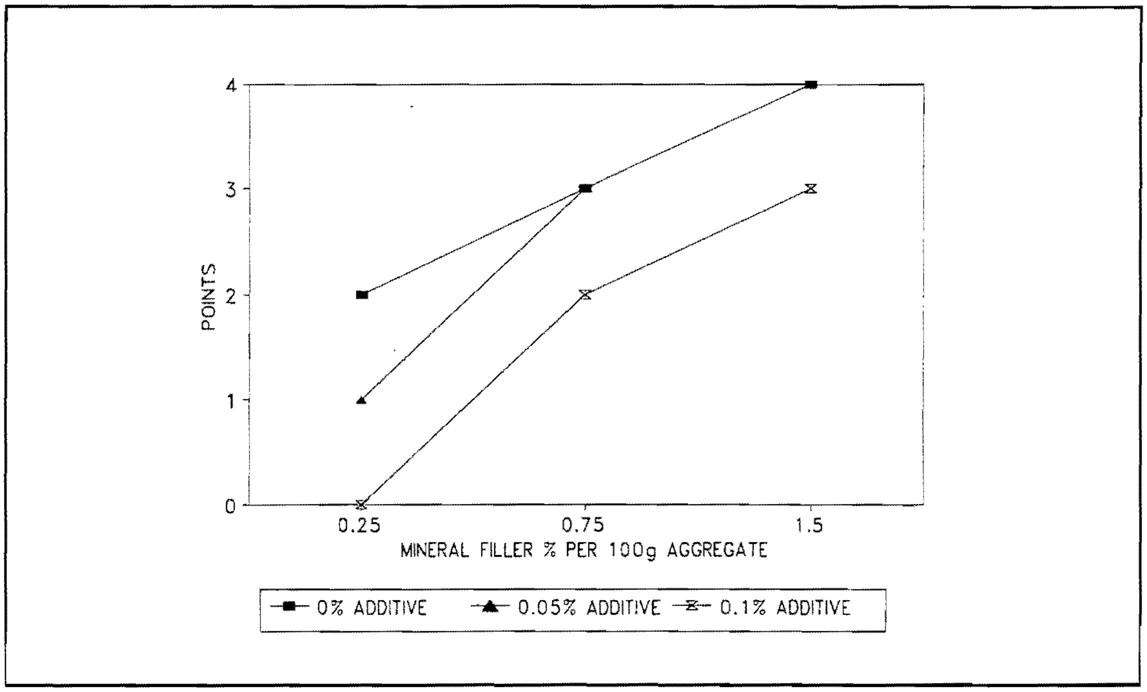

Figure 70. Schulze-Breuer procedure for aggregate mineral filler compatibility, points for integrity against mineral filler amounts

CHAPTER 5
CONCLUSIONS

A study of laboratory test protocols for micro-surfacing was conducted to aid TxDOT in developing mixture design and evaluation procedures for micro-surfacing. Based on statistical analysis of the findings, the researchers submit the following conclusions.

1. The reliability of determining mixture quality of micro-surfacing through the use of the proposed International Slurry Surfacing Association (ISSA) mix design tests investigated in this report is questionable. Specific tests such as the modified wet cohesion test and the cured cohesion test provide reasonably consistent test results. The 6-day soak wet track abrasion test appears to be capable of providing reasonable results at selected total fluid levels. Consistency in differentiating between the various formulations of all material combinations has been demonstrated for those tests. The loaded wheel test does not provide very precise results. It does not distinguish accurately enough between formulations of the same material, nor does it distinguish between the same formulations of different materials.

2. Consistency for the loaded wheel test is poor which implies that the test method is vague and permits a wide range of interpretation. The prescribed method of shaking off loose sand on a compacted sample is very imprecise. While conducting the experiments, it was determined that the amount of water in the mixture had a profound influence on the sand adhered. By changing only the quantity of water in mixtures with the same quantity of emulsion and cement, the amount of sand adhered increased or decreased. It appears that the amount of sand adhered to the sample is not sensitive to the amount of asphalt emulsion or asphalt cement present in the mix. The high k values observed represent imprecision within material and lend credence to that fact.

3. The 1-hour soak wet track abrasion test yields substantial within formulation variation. This indicates that with certain material combinations, the 1-hour soak test may yield consistently imprecise results.

4. The abrasion part of the Schulze-Breuer and Ruck procedures provides reasonable test responses. However, the measurement scale of the integrity part is insensitive. Normally, after boiling, the samples disintegrate very badly. Because the sample is small, the remaining coherent mass is usually insignificant after 30 minutes of rigorous boiling.

5. After investigating the trends exhibited by varying the material constituents of micro-surfacing, two major issues are apparent.

a. The amount of mineral filler in the mixture greatly influences the magnitude of the test response for all the tests investigated. However, each mixture formulation behaves in a unique manner. The response of a particular mixture also depends largely on the amount of water used in formulating the mixture. This is particularly evident with the 6-day soak wet track abrasion test. Samples which are formulated with high water contents have a flushed surface and yield uniform results. It appears that the total liquid content of a sample has a great deal of influence on the variability of the responses obtained with each test. The tests will be more useful if the variability in the responses can be limited to an acceptable range. To achieve that, there must be a consistent method to define and correlate with the test responses the liquid contents with which mixtures exhibit uniform characteristics. At that liquid content, the consistency of the mixture has been defined.

b. Additive amount has a large effect on cohesion values, especially early cohesions at 30 minutes. Higher levels also affect 60-minute cohesions. It has little effect on 24-hour cured cohesion results. Provided adequate curing time is allowed for a sample before testing, the amount of additive used in formulating a sample mixture does not greatly influence the test response. However, it is advisable to use higher quantities of mineral filler (1.5 percent or greater) whenever a high amount of additive is used in formulating the mixture.

CHAPTER 6
RECOMMENDATIONS

1. The use of the Modified Wet Cohesion Tests and the Cured Cohesion test for the investigation of set and cure characteristics of mixture formulations is recommended.

2. The use of the 1-hour soak test for water susceptibility and minimum asphalt cement content should be discontinued.

3. The 6-day soak Wet Track Abrasion Test should be modified and used to investigate the minimum asphalt cement requirements. The modifications in the test procedure should include a method for defining the water content at which samples should be tested. Secondly, the required surface texture of the sample must also be defined.

4. The Loaded Wheel Test is not a precise test. It is doubtful whether it distinguishes appropriately between material variations. Its use to determine maximum asphalt cement content is not recommended.

5. The abrasion part of the Schulze-Breuer and Ruck procedures produces reasonable results at fixed mineral filler content with no additive. However, it also seems to be sensitive to the type of asphalt cement used. As an aggregate filler compatibility test, it maybe useful. It is recommended that it be further evaluated.

6. The Ruck procedure which produces the integrity part of the Schulze-Breuer and Ruck procedures is not a very precise test. Certain mixture combinations have been known to fail this procedure all the time but have, nevertheless, performed adequately in the field. An investigation needs to be performed to determine the limitations of this test before its adoption.

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APPENDIX

TEST RESULTS

Introduction

This Appendix contains results for each test replicate. There were four material combinations. The material variant within each material combination is the quantity of asphalt cement. At the bottom of each table, the mean and standard deviations are given.

Table A-1. Modified Wet Cohesion and Cured Cohesion test results for Delta aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	9.0	9.5	22.0
2	10.0	10.5	22.5
3	8.0	9.0	22.5
4	8.5	10.0	23.0
5	8.0	10.5	21.0
Mean	8.7	9.9	22.2
s	0.8	0.7	0.8

Table A-2. Wet Track Abrasion 1-hour soak test results for Delta aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	595.01	582.56	364.2	33.79
2	593.09	588.22	142.4	13.22
3	553.21	535.24	525.6	48.78
4	590.10	548.33	1221.8	113.38
5	574.93	550.68	709.3	65.82
Mean	581.27	561.01	592.7	55.00
s	17.56	23.11	408.9	37.95

Table A-3. Wet Track Abrasion 6-day soak test results for Delta aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	561.94	550.11	346.0	32.11
2	557.66	548.31	273.5	25.38
3	524.44	515.00	276.1	25.62
4	572.37	563.23	267.3	24.81
5	567.94	554.47	394.0	36.56
Mean	556.87	546.22	311.4	28.90
s	18.98	18.38	56.2	5.22

Table A-4. Loaded Wheel Test results for Delta aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	(g/ft^2)
1	321.67	329.78	598.617	55.61
2	316.56	325.41	653.238	60.69
3	326.78	335.23	623.713	57.94
4	309.13	317.94	650.285	60.41
5	315.43	323.61	603.784	56.09
Mean	317.91	326.39	625.93	58.15
s	6.67	6.51	25.40	2.36

Table A-5. Schulze-Breuer and Ruck results for Delta aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	40.418	43.793	3.375	3.947	0.000	0.00	90.0
2	41.013	44.425	3.412	3.632	0.000	0.00	90.0
3	37.990	41.036	3.046	3.035	0.000	0.00	90.0
4	39.893	43.175	3.282	3.267	0.000	0.00	90.0
5	39.132	42.300	3.168	1.507	0.000	0.00	90.0
Mean	39.689	42.946	3.257	3.078	0.000	0.00	90.0
s	1.175	1.325	0.151	0.944	0.000	0.00	0.00

Table A-6. Schulze-Breuer and Ruck Compatibility Classification for Delta aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	0	0
Integrity	0	0
Adhesion	A	4
Total		4

Table A-7. Modified Wet Cohesion and Cured Cohesion test results for Delta aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	8.0	8.0	20.0
2	11.0	6.5	21.5
3	7.0	9.0	22.5
4	7.0	8.0	22.0
5	7.0	9.0	21.0
Mean	8.0	8.1	21.4
s	1.7	1.0	1.0

Table A-8. Wet Track Abrasion 1-hour soak test results for Delta aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	509.43	482.24	795.3	73.80
2	508.98	475.12	990.4	91.91
3	581.63	554.07	806.1	74.81
4	529.85	507.10	665.4	61.75
5	529.95	499.32	895.9	83.14
Mean	533.35	503.81	830.6	77.08
s	41.82	43.67	121.4	11.26

Table A-9. Wet Track Abrasion 6-day soak test results for Delta aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	718.65	638.53	2343.5	217.48
2	643.81	556.09	2565.8	238.11
3	676.68	617.65	1726.6	160.23
4	708.45	612.39	2809.8	260.75
5	710.11	592.09	3452.1	320.35
Mean	691.54	603.35	2579.6	239.38
s	31.08	31.16	632.0	58.65

Table A-10. Loaded Wheel Test results for Delta aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	(g/ft^2)
1	323.48	336.95	994.3	92.37
2	332.22	343.77	852.5	79.20
3	327.45	339.51	890.2	82.70
4	329.93	341.51	854.7	79.41
5	330.23	340.80	780.2	72.48
Mean	328.66	340.51	874.4	81.23
s	3.36	2.52	78.0	7.25

Table A-11. Schulze-Breuer and Ruck results for Delta aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g) (g)	SSD Weight (g) (g)	Absorption Weight (g) (%)	Abraded Weight (%)	Weight After Boiling	Integrity	Adhesion
1	38.650	40.966	2.316	2.545	28.000	72.88	. 90
2	38.954	41.300	2.346	2.477	34.212	88.12	90
3	38.048	40.315	2.267	2.708	30.531	81.18	90
4	38.386	40.737	2.351	2.852	0.00	0.00	90
5	38.815	41.300	2.485	2.947	0.00	0.00	90
Mean	38.571	40.924	2.353	2.706	18.549	48.44	90
s	0.361	0.415	0.081	0.199	17.076	44.54	0

Table A-12. Schulze-Breuer and Ruck Compatibility Classification for Delta aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	0	0
Integrity	D	1
Adhesion	A	4
Total		5

Table A-13. Modified Wet Cohesion and Cured Cohesion test results for Delta aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	17.0	8.0	22.0
2	16.0	7.5	21.5
3	17.0	8.0	22.5
4	16.5	8.0	20.0
5	17.0	8.5	21.0
Mean	14.7	8.0	21.4
s	0.4	0.4	1.0

Table A-14. Wet Track Abrasion 1-hour soak test results for Delta aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	721.56	707.35	415.6	38.57
2	714.27	699.97	418.3	38.82
3	711.34	695.49	463.6	43.02
4	721.91	701.21	605.5	56.19
5	717.59	701.11	482.0	44.73
Mean	717.33	701.03	477.0	44.27
s	4.59	4.24	77.3	7.18

Table A-15. Wet Track Abrasion 6-day soak test results for Delta aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Weight (g)	Weight (g)	Value (g/m^2)	(g/ft^2)
1	723.14	698.42	723.1	67.10
2	719.24	690.51	840.4	77.98
3	711.98	683.51	832.7	77.28
4	722.39	688.19	1000.3	92.83
5	719.67	682.54	1086.1	100.79
Mean	719.28	688.63	896.5	83.20
s	4.42	6.38	144.9	13.45

Table A-16. Loaded Wheel Test results for Delta aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	(g/ft^2)
1	317.08	334.29	1270.3	118.01
2	275.09	289.97	1098.3	102.03
3	293.75	306.9	970.6	90.17
4	346.04	361.61	1149.3	106.77
5	331.74	348.05	1203.9	111.84
Mean	312.74	328.16	1138.5	105.76
s	28.58	29.42	113.5	10.55

Table A-17. Schulze-Breuer and Ruck results for Delta aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	39.450	40.830	1.380	0.850	32.000	80.04	90.0
2	39.980	41.280	1.300	1.500	34.212	86.00	90.0
3	40.090	41.710	1.620	1.080	0.00	0.00	90.0
4	39.490	40.650	1.160	1.030	0.00	0.00	90.0
5	39.230	40.370	1.140	0.940	37.000	93.84	90.0
Mean	39.648	40.968	1.320	1.080	20.642	51.98	90.0
s	0.369	0.530	0.195	0.251	18.927	47.70	0.00

Table A-18. Schulze-Breuer and Ruck Compatibility Classification for Delta aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	C	2
Integrity	C	2
Adhesion	A	4
Total		8

Table A-19. Modified Wet Cohesion and Cured Cohesion test results for Delta aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	12.5	12.5	19.5
2	13.0	13.0	20.0
3	12.0	13.0	20.0
4	13.0	14.0	20.5
5	13.0	12.0	20.0
Mean	12.7	12.9	20.0
s	0.4	0.7	0.4

Table A-20. Wet Track Abrasion 1-hour soak test results for Delta aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	738.64	719.58	557.5	51.74
2	728.80	715.24	396.6	36.81
3	735.70	703.30	947.7	87.95
4	727.95	706.08	639.7	59.36
5	851.23	789.59	1803.0	167.32
Mean	756.46	726.76	868.9	80.63
s	53.17	35.74	559.3	51.90

Table A-21. Wet Track Abrasion 6-day soak test results for Delta aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	605.63	596.40	270.0	25.05
2	625.73	622.44	96.2	8.93
3	617.77	611.41	186.0	17.26
4	618.76	583.33	1036.3	96.17
5	686.15	674.48	341.3	31.68
Mean	630.81	617.61	386.0	35.82
s	31.77	35.07	374.9	34.79

Table A-22. Loaded Wheel Test results for Delta aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand (g/m^2)	(g/ft^2)
1	411.87	423.67	871.0	80.91
2	401.42	409.58	602.3	55.95
3	402.43	413.57	822.3	76.39
4	409.71	421.77	890.2	82.70
5	414.56	426.40	873.9	81.19
Mean	408.00	419.00	811.9	75.43
s	5.81	7.11	119.9	11.14

Table A-23. Schulze-Breuer and Ruck results for Delta aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	38.863	41.875	3.012	1.693	37.655	93.71	90.0
2	39.105	42.021	2.916	1.444	37.786	93.12	90.0
3	39.105	42.315	3.210	1.140	39.782	96.62	90.0
4	38.305	41.111	2.806	1.406	36.952	93.07	90.0
5	38.454	41.350	2.896	1.444	37.485	93.93	90.0
Mean	38.766	41.734	2.968	1.425	37.932	94.09	90.0
s	0.371	0.494	0.154	0.196	1.082	1.46	0.0

Table A-24. Schulze-Breuer and Ruck Compatibility Classification for Delta aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	D	1
Integrity	A	4
Adhesion	A	4
		9

Table A-25. Modified Wet Cohesion and Cured Cohesion test results for Delta aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Cohesion Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	21.0	20.0	19.0
2	18.0	18.5	20.0
3	20.0	16.0	18.0
4	17.0	14.0	16.5
5	17.5	15.0	17.5
Mean	18.7	16.7	18.2
s	1.7	2.5	1.4

Table A-26. Wet Track Abrasion 1-hour soak test results for Delta aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	652.87	649.27	105.3	9.77
2	582.35	575.00	215.0	19.95
3	706.40	698.31	236.6	21.96
4	747.78	731.80	467.4	43.38
5	754.34	747.72	193.6	17.97
Mean	688.75	680.42	243.6	22.61
s	71.95	69.95	134.7	12.50

Table A-27. Wet Track Abrasion 6-day soak test results for Delta aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	Wear Value (g/ft^2)
1	759.68	732.89	783.6	72.72
2	739.86	699.51	1180.2	109.53
3	745.45	723.86	631.5	58.60
4	737.98	709.56	831.3	77.14
5	742.65	714.56	821.6	76.25
Mean	745.12	716.08	849.7	78.85
s	8.61	12.87	201.5	18.70

Table A-28. Loaded Wheel Test results for Delta aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand (g/m^2)	Weight of Adhered Sand (g/ft^2)
1	367.16	376.99	725.6	67.41
2	340.45	349.80	690.1	64.11
3	384.91	397.38	920.4	85.51
4	339.94	353.23	981.0	91.13
5	342.61	354.29	862.1	80.09
Mean	355.01	366.34	835.8	77.65
s	20.21	20.42	124.8	11.59

Table A-29. Schulze-Breuer and Ruck results for Delta aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	40.600	42.870	2.270	1.960	40.590	99.22	90.00
2	40.780	43.120	2.340	1.330	41.000	98.11	90.00
3	40.860	42.960	2.100	1.200	41.020	98.23	90.00
4	38.900	40.310	1.410	0.730	38.940	98.38	90.00
5	40.510	42.960	2.450	1.670	40.890	99.03	90.00
Mean	40.330	42.444	2.114	1.378	40.488	98.59	90.00
s	0.811	1.196	0.414	0.468	0.882	0.50	0.00

Table A-30. Schulze-Breuer and Ruck Compatibility Classification for Delta aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	D	1
Integrity	A	4
Adhesion	A	4
		9

Table A-31. Modified Wet Cohesion and Cured Cohesion test results for Delta aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	17.0	19.0	21.5
2	17.0	15.5	22.0
3	19.5	20.5	21.5
4	15.0	21.0	22.0
5	19.0	17.0	21.0
Mean	17.5	18.6	21.6
s	1.8	2.3	0.4

Table A-32. Wet Track Abrasion 1-hour soak test results for Delta aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	793.25	782.62	310.9	28.85
2	806.23	799.03	210.6	19.54
3	514.83	501.70	384.1	35.64
4	795.37	786.70	253.6	23.53
5	788.66	786.33	68.2	6.32
Mean	739.67	731.28	245.5	22.78
s	125.85	128.49	118.5	11.00

Table A-33. Wet Track Abrasion 6-day soak test results for Delta aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	688.69	662.59	763.4	70.85
2	484.12	461.68	656.4	60.91
3	569.07	547.42	633.3	58.77
4	790.24	783.16	207.1	19.22
5	691.14	679.91	328.5	30.48
Mean	644.65	626.95	517.7	48.04
s	119.14	124.62	237.3	22.02

Table A-34. Loaded Wheel Test results for Delta aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand (g/m^2)	(g/ft^2)
1	379.56	394.74	1120.5	104.09
2	344.50	355.89	840.7	78.10
3	351.08	363.24	897.6	83.38
4	326.63	345.84	1417.9	131.73
5	376.62	393.42	1240.0	115.20
Mean	355.68	370.63	1103.3	102.50
s	22.35	22.29	239.4	22.24

Table A-35. Schulze-Breuer and Ruck results for Delta aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	40.180	42.190	2.010	1.050	39.760	96.65	90.00
2	40.260	42.390	2.130	1.020	40.050	96.81	90.00
3	39.890	42.430	2.540	2.150	40.220	99.85	90.00
4	40.320	42.810	2.490	1.030	39.850	95.38	90.00
Mean	40.163	42.455	2.293	1.313	39.970	97.17	90.00
s	0.191	0.259	0.262	0.558	0.206	1.90	0

Table A-36. Schulze Breuer and Ruck Compatibility Classification for Delta aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	D	1
Integrity	A	4
Adhesion	A	4
		9

Table A-37. Modified Wet Cohesion and Cured Cohesion test results for TransPecos aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	8.0	10.0	19.0
2	9.0	9.5	20.0
3	8.5	9.5	18.5
4	9.0	11.0	21.0
5	10.0	10.5	20.5
Mean	8.9	10.1	19.8
s	0.7	0.7	1.0

Table A-38. Wet Track Abrasion 1-hour soak test results for TransPecos aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	714.05	705.67	245.1	22.75
2	716.45	707.98	247.7	22.99
3	705.34	692.54	374.4	34.74
4	719.02	701.89	501.1	46.50
5	703.45	686.43	497.8	46.20
Mean	711.66	698.90	373.2	34.64
s	6.90	9.13	126.5	11.74

Table A-39. Wet Track Abrasion 6-day soak test results for TransPecos aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	712.34	692.87	569.5	52.85
2	698.45	681.12	506.9	47.04
3	718.39	693.12	739.1	68.59
4	707.63	693.98	399.3	37.05
5	705.25	692.71	366.8	34.04
Mean	708.41	690.76	516.3	47.91
s	7.50	5.41	148.9	13.81

Table A-40. Loaded Wheel Test results for TransPecos aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	(g/ft^2)
1	362.95	372.10	675.4	62.74
2	350.97	357.24	462.8	42.99
3	366.28	373.94	565.4	52.53
4	356.3	365.73	696.0	64.66
5	341.71	348.64	511.5	47.52
Mean	355.64	363.53	582.2	54.09
s	9.78	10.58	101.5	9.43

Table A-41. Schulze-Breuer and Ruck results for TransPecos aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	39.430	40.563	1.133	0.693	34.150	85.65	90.00
2	39.560	40.721	1.161	1.051	35.980	90.70	90.00
3	39.810	40.342	0.532	0.782	32.570	82.33	90.00
4	40.210	41.821	1.611	1.041	36.360	89.16	90.00
5	39.960	41.670	1.710	0.690	36.390	88.80	90.00
Mean	39.794	41.023	1.229	0.851	35.090	87.33	90.00
s	0.311	0.675	0.468	0.181	1.683	3.34	0.00

Table A-42. Schulze-Breuer and Ruck Compatibility Classification for TransPecos aggregate and 10% Koch emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	B	3
Integrity	B	3
Adhesion	A	4
Total		10

Table A-43. Modified Wet Cohesion and Cured Cohesion test results for TransPecos aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	9.0	10.0	21.0
2	7.5	11.0	20.5
3	6.0	9.5	19.5
4	6.5	10.0	21.0
5	8.0	10.5	23.0
Mean	7.4	10.2	21.0
s	1.2	0.6	1.3

Table A-44. Wet Track Abrasion 1-hour soak test results for TransPecos aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	738.61	736.67	56.7	5.27
2	771.97	768.65	97.1	9.01
3	691.48	689.39	61.1	5.67
4	756.39	753.71	78.4	7.27
5	743.81	739.01	140.4	13.03
Mean	740.45	737.49	86.8	8.05
s	30.25	29.79	34.0	3.15

Table A-45. Wet Track Abrasion 6-day soak test results for TransPecos aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	761.23	736.67	718.4	66.67
2	774.97	743.34	925.2	85.86
3	769.45	739.45	877.5	81.43
4	753.71	732.56	618.6	57.41
5	749.12	721.28	814.3	75.57
Mean	761.70	734.66	790.8	73.39
s	10.71	8.45	123.5	11.46

Table A-46. Loaded Wheel Test results for TransPecos aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	(g/ft^2)
1	343.30	352.47	676.9	62.88
2	345.3	352.21	510.0	47.38
3	323.4	333.56	749.9	69.67
4	351.45	364.1	933.7	86.74
5	335.67	342.45	500.4	46.49
Mean	339.82	348.96	674.2	62.63
s	10.77	11.53	180.4	16.76

Table A-47. Schulze-Breuer and Ruck results for TransPecos aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	39.380	43.280	3.900	3.440	0.000	0.00	90.00
2	39.320	43.240	3.920	2.610	0.000	0.00	90.00
3	39.220	43.640	4.420	5.050	0.000	0.00	90.00
4	39.970	43.810	3.840	4.360	0.000	0.00	90.00
5	39.500	42.810	3.310	5.600	0.000	0.00	90.00
Mean	39.478	43.356	3.878	4.212	0.000	0.00	90.00
s	0.293	0.389	0.394	1.206	0.000	0.00	0.00

Table A-48. Schulze-Breuer and Ruck Compatibility Classification for TransPecos aggregate and 12% Koch emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	0	0
Integrity	0	0
Adhesion	B	3
Total		3

Table A-49. Modified Wet Cohesion and Cured Cohesion test results for TransPecos aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	6.5	8.0	25.0
2	6.0	7.5	22.5
3	6.5	9.0	23.0
4	6.0	8.0	23.0
5	6.0	9.0	22.0
Mean	6.2	8.3	23.1
s	0.3	0.7	1.1

Table A-50. Wet Track Abrasion 1-hour soak test results for TransPecos aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	Wear Value (g/ft^2)
1	666.42	659.98	188.4	17.48
2	715.55	707.79	227.0	21.06
3	701.35	690.11	328.8	30.51
4	719.82	713.43	186.9	17.35
5	721.09	709.85	328.8	30.51
Mean	704.85	696.23	252.0	23.38
s	22.87	22.17	71.9	6.68

Table A-51. Wet Track Abrasion 6-day soak test results for TransPecos aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	Wear Value (g/ft^2)
1	680.60	662.37	533.2	49.48
2	717.71	631.34	2526.3	234.44
3	720.45	689.59	902.7	83.77
4	713.34	675.13	1117.6	103.72
5	707.86	678.43	860.8	79.88
Mean	707.99	667.37	1188.1	110.26
s	16.04	22.36	776.7	72.08

Table A-52. Loaded Wheel Test results for TransPecos aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	Weight of Adhered Sand After 100 Cycles (g/ft^2)
1	321.67	329.78	598.6	55.61
2	316.56	325.41	653.2	60.69
3	326.78	335.23	623.7	57.94
4	309.13	317.94	650.3	60.41
5	315.43	323.61	603.8	56.09
Mean	317.91	326.39	625.9	58.15
s	6.67	6.51	25.4	2.36

Table A-53. Schulze-Breuer and Ruck results for TransPecos aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

Sample #	Weight Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Boiling (g)	Weight After Integrity (g)	Adhesion (%)	(%)
1	39.690	41.800	2.110	1.970	0.000	0.00	90.00
2	40.170	42.310	2.140	1.610	0.000	0.00	90.00
3	39.550	41.300	1.750	1.650	35.890	90.52	90.00
4	40.740	42.630	1.890	2.710	40.760	102.10	90.00
5	40.640	42.590	1.950	1.740	0.000	0.00	90.00
Mean	40.158	42.126	1.968	1.936	15.330	38.52	90.00
s	0.538	0.568	0.161	0.455	21.062	52.91	0.00

Table A-54. Schulze-Breuer and Ruck Compatibility Classification for TransPecos aggregate and 14% Koch emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	D	1
Integrity	D	1
Adhesion	A	4
Total		6

Table A-55. Modified Wet Cohesion and Cured Cohesion test results for TransPecos aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	17.0	17.0	24.0
2	15.5	17.5	25.0
3	16.0	16.5	26.0
4	15.0	16.5	22.5
5	14.0	18.0	25.0
Mean	15.50	17.10	24.50
s	1.12	0.65	1.32

Table A-56. Wet Track Abrasion 1-hour soak test results for TransPecos aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	566.41	559.08	214.4	19.90
2	560.81	543.89	494.9	45.93
3	579.57	564.85	430.6	39.96
4	506.86	499.85	205.0	19.03
5	548.86	540.57	242.5	22.50
Mean	552.50	541.65	317.5	29.46
s	27.80	25.47	135.2	12.55

Table A-57. Wet Track Abrasion 6-day soak test results for TransPecos aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	476.95	440.88	1055.0	97.91
2	556.87	531.23	750.0	69.60
3	563.67	529.45	1000.9	92.89
4	503.35	446.77	1655.0	153.58
5	507.99	493.22	432.0	40.09
Mean	521.77	488.31	978.6	90.81
s	37.17	43.40	451.3	41.88

Table A-58. Loaded Wheel Test results for TransPecos aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Weight (g)	Weight (g)	Weight After 100 Cycles (g/m^2)	(g/ft^2)
1	275.55	284.36	650.3	60.41
2	266.27	275.10	651.8	60.55
3	271.59	281.99	767.6	71.31
4	262.66	273.36	789.8	73.37
5	250.28	260.59	761.0	70.70
Mean	265.27	275.08	724.1	67.27
s	9.72	9.31	67.6	6.28

Table A-59. Schulze-Breuer and Ruck results for TransPecos aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	35.898	39.110	3.212	2.092	35.360	95.52	90.00
2	38.347	42.057	3.710	1.795	29.061	72.18	90.00
3	39.885	43.678	3.793	1.905	40.597	97.18	90.00
4	39.875	43.380	3.505	1.596	40.318	96.49	90.00
5	39.880	43.506	3.626	1.485	39.920	95.00	90.00
Mean	38.777	42.346	3.569	1.775	37.051	91.28	90.00
s	1.741	1.920	0.226	0.242	4.954	10.71	0.00

Table A-60. Schulze-Breuer and Ruck Compatibility Classification for TransPecos aggregate and 10% Ergon emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	D	1
Integrity	A	4
Adhesion	A	4
Total		9

Table A-61. Modified Wet Cohesion and Cured Cohesion test results for TransPecos aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	19.5	24.0	24.0
2	19.5	20.0	23.0
3	15.0	21.0	21.0
4	22.0	18.5	24.0
5	19.5	20.0	22.0
Mean	19.1	20.7	22.8
s	2.5	2.0	1.3

Table A-62. Wet Track Abrasion 1-hour soak test results for TransPecos aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	606.53	592.43	412.4	38.27
2	560.81	543.89	494.9	45.93
3	579.57	564.85	430.6	39.96
4	589.45	575.63	404.2	37.51
5	596.34	580.45	464.8	43.13
Mean	586.54	571.45	441.4	40.96
s	17.43	18.31	37.9	3.52

Table A-63. Wet Track Abrasion 6-day soak test results for TransPecos aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	704.56	663.96	1187.5	110.20
2	648.32	597.15	1496.7	138.90
3	766.42	749.36	499.0	46.31
4	730.08	684.27	1339.9	124.35
5	678.06	663.13	436.7	40.53
Mean	705.49	671.57	992.0	92.06
s	45.66	54.50	491.3	45.59

Table A-64. Loaded Wheel Test results for TransPecos aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	(g/ft^2)
1	314.54	327.00	919.7	85.44
2	350.48	359.34	654.0	60.75
3	349.92	356.49	484.9	45.05
4	330.45	339.06	635.5	59.04
5	309.27	328.09	1389.1	129.05
Mean	330.93	342.00	816.7	75.87
s	19.24	15.31	356.3	33.10

Table A-65. Schulze-Breuer and Ruck results for TransPecos aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	40.088	42.828	2.740	0.845	41.013	97.69	90.00
2	35.962	38.067	2.105	0.849	35.972	96.65	90.00
3	39.306	41.853	2.547	0.712	40.970	99.58	90.00
4	35.572	37.697	2.125	0.762	36.004	97.48	90.00
5	37.958	40.246	2.288	0.611	38.402	96.89	90.00
Mean	37.777	40.138	2.361	0.756	38.472	97.66	90.00
s	1.992	2.260	0.276	0.099	2.502	1.16	0.00

Table A-66. Schulze-Breuer and Ruck Compatibility Classification for TransPecos aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	B	3
Integrity	A	4
Adhesion	A	4
Total		11

Table A-67. Modified Wet Cohesion and Cured Cohesion test results for TransPecos aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	30 min (kg-cm)	60 min. (kg-cm)	24 hr. (kg-cm)
1	14.5	15.0	20.0
2	14.0	17.5	20.5
3	14.0	16.5	21.0
4	14.0	14.0	16.5
5	14.5	16.0	19.0
Mean	14.2	15.8	19.0
s	1.0	1.6	0.6

Table A-68. Wet Track Abrasion 1- hour soak test results for TransPecos aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	550.45	548.71	50.90	4.72
2	604.66	604.52	4.10	0.38
3	682.34	680.34	58.50	5.43
4	689.99	687.73	66.98	6.22
5	617.18	616.03	33.64	3.12
Mean	628.92	627.46	42.82	3.97
s	58.02	57.63	24.89	2.31

Table A-69. Wet Track Abrasion 6-day soak test results for TransPecos aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Wear Value (g/m^2)	(g/ft^2)
1	560.72	545.99	430.8	39.98
2	606.11	589.74	478.8	44.43
3	685.56	672.78	373.8	34.69
4	679.45	662.76	488.2	45.30
5	654.66	649.97	137.2	12.73
Mean	637.30	624.25	381.76	35.43
s	53.02	54.35	144.07	13.37

Table A-70. Loaded Wheel Test results for TransPecos aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Original Weight (g)	Final Weight (g)	Weight of Adhered Sand After 100 Cycles (g/m^2)	(g/ft^2)
1	268.65	281.76	967.68	89.90
2	270.49	284.76	1053.30	97.85
3	363.11	370.9	575.00	53.42
4	378.61	387.46	653.24	60.69
5	280.42	294.00	1002.37	93.12
Mean	312.26	323.78	850.32	78.99
s	53.96	51.11	219.51	20.39

Table A-71. Schulze-Breuer and Ruck results for TransPecos aggregate and 14% Ergon emulsion with 12% water and 0.75% mineral filler

Sample #	Dry Weight (g)	SSD Weight (g)	Absorption Weight (g)	Abraded Weight (g)	Weight After Boiling (g)	Integrity (%)	Adhesion (%)
1	34.834	36.525	1.691	0.263	36.071	99.47	90.00
2	37.878	40.106	2.228	0.444	39.588	99.81	90.00
3	39.559	41.572	2.013	0.174	41.203	99.53	90.00
4	40.631	42.673	2.042	0.304	42.268	99.76	90.00
5	39.995	41.843	1.848	0.127	41.465	99.40	90.00
Mean	38.579	40.544	1.964	0.262	40.119	99.60	90.00
s	2.329	2.430	0.204	0.123	2.463	0.18	0.00

Table A-72. Schulze-Breuer and Ruck Compatibility Classification for TransPecos aggregate and 12% Ergon emulsion with 12% water and 0.75% mineral filler

	Grade Rating	Point Rating
Abrasion	A	4
Integrity	A	4
Adhesion	A	4
Total		12