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Development of Field Validation Tests for Coal-Tar Emulsions

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16. Abstract

Field quality assurance and quality control (QA/QC) programs represent the most important step toward ensuring the construction of a successful project. However, in order for QA/QC programs to be implemented, a set of simple and yet effective tests must be available which can be conducted in the field during the construction process. The objective of this study was to investigate the available QA/QC programs for coal-tar emulsions and to further evaluate the ones that proved reliable. The research evaluated four different tests. Two of these tests were proven reliable and yet simple and were recommended for inclusion in a QA/QC program.

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EXECUTIVE SUMMARY

This study evaluated four different tests for potential use in a quality assurance and quality control (QA/QC) program for coal-tar emulsions. These tests include; (a) field density measurement, (b) percent weight wet sand, (c) mix design verification, and (d) field fuel resistance test. The first three tests were evaluated in the laboratory using coal-tar emulsions specially prepared to introduce variations into the mixtures. The field fuel resistance test was evaluated on field sections with variable levels of aging. The tests were evaluated based on the following criteria: (a) technical merit, (b) field experience, (c) field applicability, and (d) cost of test equipment.

The laboratory evaluation proved that the field density measurement is not sensitive enough to variations in the mix components and therefore, was not recommended for inclusion in a QA/QC program. The percent weight wet sand test was proven sensitive to changes in the sand content and was recommended for inclusion in a QA/QC program. The mix verification program was proven sensitive to changes in the mix but too expensive and difficult to be conducted in the field. This program was recommended as a backup evaluation in the case that the percent weight wet sand indicates the existence of a problem.

The field experiment indicated that the fuel resistance test is a reliable and practical test which should be included in a QA/QC program The failure criterion should be considered as 0.2 inch gasoline penetration and noticeable damage after 30 minutes period.

1. INTRODUCTION.

As the use of coal-tar pitch emulsion seal coats on airport pavements continues, there is a great need to develop a procedure to check the quality of the product as it is delivered to the job site. Currently, the material is designed in the laboratory through a rigorous mix design procedure; however, there is no control on the quality of the product that is delivered to the job site. Previous research studies have shown that the addition of too much sand to the mix will significantly influence its fuel resistance property, and the addition of too much water will greatly influence its long term durability [1]. It should be noted that the addition of both sand and water will generate higher profit for the contractor since a higher coverage rate will be achieved with a constant amount of coal-tar pitch emulsion.

Therefore, there may be a tendency for the contractor to deliver products that do not meet the originally specified mix design unless a quality control and assurance program is developed and implemented. This process is known as the quality assurance/quality control (QA/QC) which is implemented on almost all materials used in airport and highway construction. The research activity described in this report evaluated the available QA/QC programs for coal-tar pitch emulsions for potential adaptation into the Federal Aviation Administration (FAA) specification.

The FAA has been supporting various research studies toward the development of performance-based specifications for coal-tar pitch emulsion seal coat for use on airport pavements [1, 2, 3]. Based on these studies, significant changes and modifications have been made to the original set of specifications. In addition to FAA sponsored studies, the Pavement Coating Technology Center (PCTC) has been conducting a highly active research and development program which complimented the FAA's program in several areas [4, 5, 6].

In 1992 the FAA sponsored a project to evaluate the impact of the various test parameters on the mix design data [1]. This study showed that some parameters may be significant while others may not be. For example, the use of a shingle or aluminum substrate does not have any impact on the results of the freeze-thaw testing, while the level of sand loading does have a significant impact on the results of the fuel resistance test [1].

In 1993 the FAA sponsored a research project entitled, "Development of Test Methods for Coal-tar Mixtures on Airport Pavements" [3]. The first task of this project was to investigate the various types of laboratory mixing procedures in an effort to replace the spoon-mixing technique with a more reliable and repeatable process. The second task was to evaluate a test for measuring the sand suspension ability of coal-tar mixtures. The third task was to investigate the possibility of developing a durability test for coal-tar emulsions. As a result of this project it is recommended to use a standard air-powered mixer in place of the spoon-mixing process. It is also recommended to continue the evaluation of the scrub test for durability evaluation because the sand suspension test did not prove to be as reliable.

In 1994 the PCTC sponsored a research program to evaluate multiple mixing devices, multiple methods for viscosity measurement, and two durability tests [4]. The recommendations of this study were:

- to use the air-powered mixer,
- to use the Brookfield viscometer for coal-tar emulsions, and
- to further investigate the scrub and wet track abrasion tests (WTAT) to evaluate the durability of coal-tar emulsions.

In 1995 the PCTC started a follow-up study on the evaluation of the scrub and WTAT tests and a study to evaluate the ability of coal-tar emulsions to protect pavements from fuel penetration and aging of the asphalt binder [5]. These studies are scheduled to be completed in December 1995. In addition, the PCTC has developed a set of generic specifications for the design and application of coal-tar emulsions with and without modifiers [6].

2. OBJECTIVE.

Coal-tar pitch emulsions are very similar to other materials such as asphalt mixtures and concrete mixtures in that their long term durability and performance are highly dependent on the quality and quantity of the materials that are being applied. The conformance of the materials to the mix design requirements is very critical, especially with a performance-based design procedure. The current FAA specification is based on performance-based tests such as the freeze-thaw and the fuel resistance tests. The performance of the mixture in these tests is highly dependent on the proportioning of the materials.

The objective of this research project is to investigate the available QA/QC programs for coal-tar pitch emulsions. Those proven reliable will be recommended for inclusion as part of the FAA specifications.

In order to achieve these objectives, the following two tasks were completed:

Task A: Review of Existing Programs
Task B: Recommendation and Implementation Plan

3. TASK A: REVIEW OF EXISTING PROGRAMS.

This task identified and reviewed the various QA/QC programs that are being used by the manufacturers and contractors of coal-tar emulsions. It was discovered that only three QA/QC programs currently exist. These programs are:

- Field density measurement
- Percent weight wet sand
- Mix design verification

In addition to the existing programs, the project team worked with coal-tar manufacturers to identify a field fuel resistant test which can be used part of the QA/QC. This provided a total of four programs to be evaluated in this project. The evaluation criteria included the following:

- Technical merit of the recommended tests
- Field experience with the recommended program
- Field applicability of the recommended program
- Cost of the program

3.1 DESCRIPTION OF SELECTED PROGRAMS.

3.1.1 Field Density Measurement.

This program relies on measuring the weight per gallon of the coal-tar emulsion that is being delivered to the job site. By comparing the field weight per gallon with the weight per gallon provided as part of the mix design, a quality assurance can be provided. The test consists of the following steps:

a. Apparatus:

1. A standard stainless steel weight per gallon cup with lid that is calibrated to contain 83.2 grams of water at 77 ± 1°F (25 ± 0.5°C). ($200.00)

2. Balance, accurate to 0.01 grams. ($2000.00)

3. Water bath capable of maintaining a temperature of 77°F. ($2500.00)

b. Procedure:

1. Obtain a coal-tar emulsion sample from the delivery truck and place it in a 77°F water bath for a minimum of 2 hours until the sample temperature reaches 77 ± 1°F.

2. Weigh the weight per gallon cup with lid on to the nearest 0.01 gm and record as tare weight (A).

3. Remove the coal-tar sample from the bath and stir until uniform. Avoid trapping air in the sample during stirring.

4. Carefully pour the emulsion into the weight per gallon cup until it is full, avoiding the entrapment of air.

5. Immediately place the lid on the full weight per gallon cup and remove the excess emulsion oozing through the orifice in the lid with a clean rag or paper towel.

6. Weigh the cup to the nearest 0.01 gm and record as the weight of emulsion and tare (B).

c. Calculations:

Calculate the weight per gallon of the coal-tar emulsion as follows:

$$D = (B-A)/10$$

Where:

A = Tare weight of the cup and lid (gm)
B = Weight of emulsion and tare (gm)
D = Weight per gallon of emulsion (lbs/gal)

3.1.2 Percent Weight Wet Sand.

This program relies on measuring the percent weight wet sand of the coal-tar emulsion that is being delivered to the job site. By comparing the field measurement with the percent weight wet sand provided as part of the mix design, a quality assurance can be provided. The test consists of the following steps:

a. Apparatus:

1. ASTM standard sieves, sizes #20 and #100. ($100.00)
2. Balance accurate to 0.01 gm. ($2000.00)
3. One pint plastic open mouth container. ($10.00)

b. Procedure:

1. Weigh the dry #100 sieve S_{wt}.

2. Place an empty and clean one pint plastic open mouth container on the balance taring it to zero.

3. Stir the emulsion sample until it is uniform.

4. Immediately after stirring, weigh 200 gm of the sample and place it into the container T_{wt}.

5. Stack the #20 sieve on top of the #100 sieve and pour the 200 gm of the emulsion into the #20 sieve. Use water to rinse clean the contents of the plastic container into the stack of sieves. Rinse any emulsion retained on the #20 sieve (it should all pass through). Remove the #20 sieve and wash off all the coal tar and water from the part of the sample that was retained on #100 sieve. It will take about four gallons of water to wash the sand clean. Do not stop the water until the sand is clean. Be careful not to splash sand over the sides of the #100 sieve.

6. Dry off all excess water from the sides and bottom of the #100 sieve using a paper towel.

7. Weigh the #100 sieve with its retained wet sand.

c. Calculations:

Calculate the percent weight wet sand as follow:

$H = \{(T_{wt} - S_{wt})/200\} \times 100$

Where:

T_{wt} = Total weight of wet sand and #100 sieve
S_{wt} = Net weight of empty and dry #100 sieve
H = Percent weight wet sand in the emulsion

3.1.3 Mix Design Verification.

This program consists of separating the various components of the coal-tar emulsion and checking them against the mix design information. The test consists of the following steps:

a. Apparatus:

1. Balance, accuracy to 0.01 gm. ($2000.00)
2. Evaporating dishes (crucibles). ($20.00 each)
3. Oven capable of maintaining 155 ± 3°C. ($2000.00)
4. Muffle furnace capable of achieving 800°C. ($2500.00)
5. Spatula. ($5.00)

b. Procedure:

1. Develop a relationship between percent solid and percent water for the coal-tar sealer that is used on the job or use a typical relationship as the one shown in figure 1.

2. Obtain one quart sample of the coal sealer from the supplier and one quart sample tar emulsion (sealer+water+sand+additive) from the delivery truck.

3. Using a spatula to stir the sample and transfer a 10 ± 1 gm into a preweighed and tared crucibles. Record the sealer sample weight (ESW_{fed}) and the emulsion sample weight (ESW_{mix}).

4. Repeat step c for three replicates.

5. Place the samples in a 155°C preheated oven for 60 minutes.

WATER VERSUS SOLIDS CONTENT, COAL-TAR-MIX DESIGN VERIFICATION

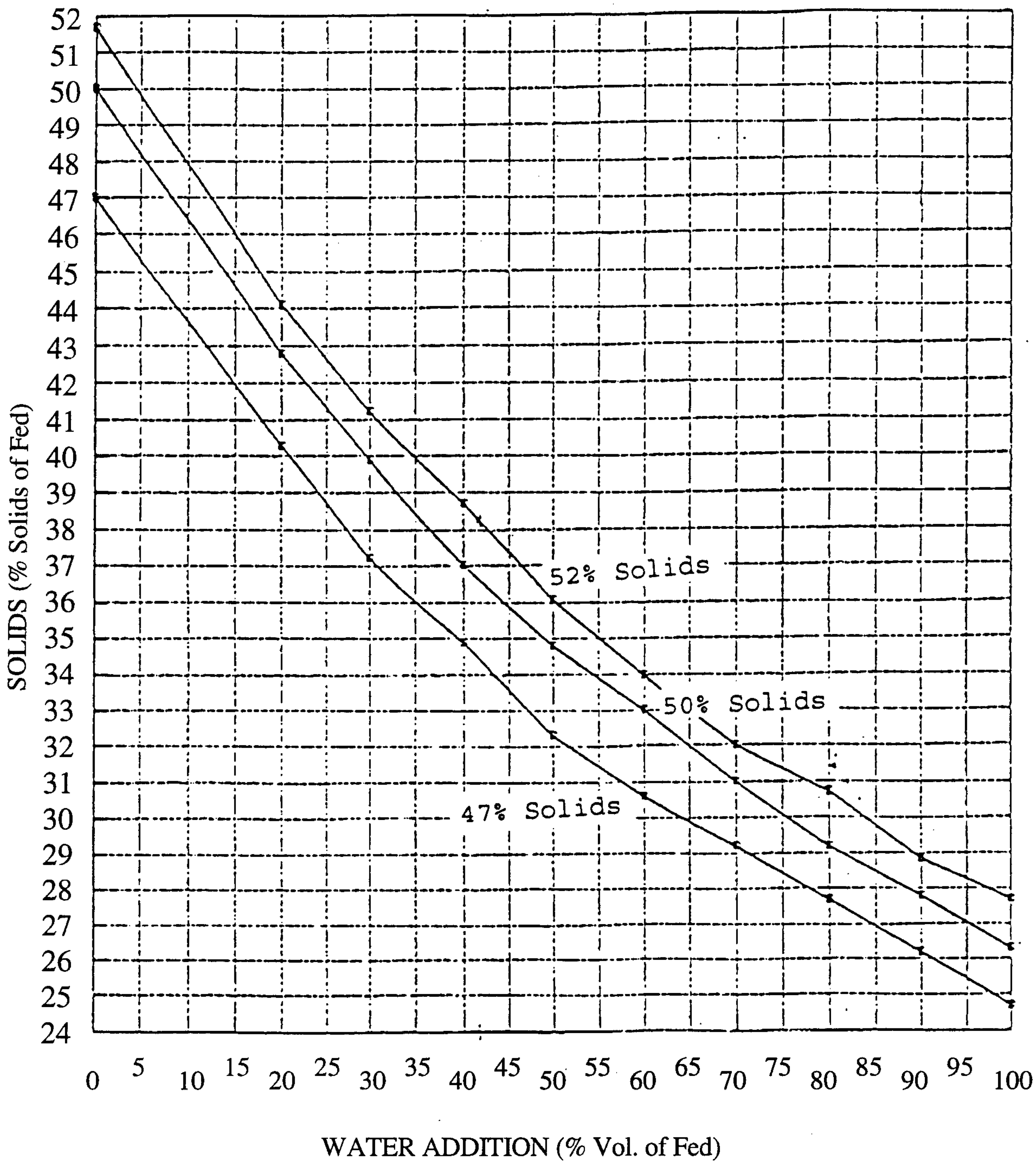

FIGURE 1. TYPICAL RELATIONSHIP BETWEEN WATER AND SOLIDS FOR COAL-TAR EMULSIONS, DEVELOPED BY BITUMINOUS TECHNOLOGIES

6. Remove the samples from the oven and weigh them as DSW_{fed} for the sealer and DSW_{mix} for the emulsion.

7. Place the samples in a muffle furnace (the starting temperature of the furnace should be close to 400°C). Bring the furnace temperature to 800°C and maintain for 60 minutes.

8. Remove samples from the furnace and weigh them as AW_{fed} for the sealer and AW_{mix} for the emulsion.

c. Calculations:

Calculate the average of three replicates as follows:

Percent solids = $(DSW_{fed}/ESW_{fed}) \times 100$

Percent ash = $(AW_{fed}/DSW_{fed}) \times 100$

$$SAND_{ADD}(gm) = \frac{(\text{percent ash} \times DSW_{mix}) - (100 \times AW_{mix})}{(\text{percent ash} - 100)}$$

Percent sand = $(SAND_{ADD}/ESW_{mix}) \times 100$

$$SOL\%MIX/\text{wo sand} = \frac{(DSW_{mix} - SAND_{ADD}) \times 100}{(ESW_{mix} - SAND_{ADD})}$$

Gallons of water per 100 gallons = (100 x Water Added (%))

$$\text{Total mix wt} = \frac{100 \times \text{sealer density (lbs/gal)} + \text{wt water}}{1 - \text{Sand Percent}}$$

Lbs of sand per 100 gallons = total mix wt - (weight of sealer + weight of water)

Where:

DSW_{mix} = The dry solid weight of the emulsion

AW_{mix} = The ash weight of the emulsion

ESW_{mix} = The original weight of the emulsion

Water added (%) = Obtained from the relationship between the percent solid and percent water (figure 1).

Report the following:

Percent solids (%)
Percent ash (%)
Percent sand (%)
Gallons of water per 100 gal. of sealer
Pounds of sand per 100 gal. of sealer

3.1.4 Field Fuel Resistance.

This test consists of measuring the fuel resistance capabilities of the coal-tar emulsion as it has been applied to the pavement. The fuel resistance of the field materials will be compared with its fuel resistance as reported in the mix design data. The test consists of the following steps:

a. Apparatus:

1. six-inch-diameter by 3-inch-high steel pipe. ($200.00)
2. Lid for the pipe. ($1.00)
3. Silicon rubber tube. ($5.00)
4. Ruler. ($1.00)

b. Procedure:

1. Locate a clean and flat surface on the sealed pavement.

2. Place the pipe on the pavement surface and seal the edge with silicon. Use your finger to push the silicon under the pipe and make sure there are no voids between the pipe and the surface so that gasoline will not flow through the sealant.

3. Cure the silicon sealant for 2.5 hours.

4. Pour one inch of gasoline inside the pipe and cover it with the lid.

5. Check how much gasoline (inches) goes through the pavement every 15 minutes by placing the ruler inside the pipe and measuring the distance between the top of pipe and the top of the gasoline.

6. Repeat the measurement for a total of one hour or until all gasoline goes through.

7. Check if gasoline is seeping out at the pipe/pavement interface.

3.2 EVALUATION OF SELECTED PROGRAMS.

As mentioned earlier, the selected programs will be evaluated against a set of criteria. These criteria cover the technical merit, the field applicability, and the cost of each of the programs. Table 1 summarizes the evaluation of the various programs against the established criteria. It can

TABLE 1. SUMMARY OF THE EVALUATION DATA FOR THE SELECTED PROGRAMS

Program	Technical Merit	Field Experience	Field Application	Cost ($)
1. Density	The method used is technically valid.	One manufacturer has used this technique in the field.	It can be easily adapted to field applications.	4,700.00
2. Wet Sand	The method used is technically valid.	One manufacturer has used this technique in the field.	It can be easily adapted to field applications.	2,110.00
3. Mix Design	The method used is technically valid.	One manufacturer has used this technique in the laboratory.	It may not be easily adaptable to field applications.	6,525.00
4. Fuel Resistance	The method used is technically valid.	One manufacturer has used this technique in the field.	It can be easily adapted to field applications.	207.00

be seen from the summary in table 1 that all of the selected programs are technically sound, which means that these procedures provide valid and useful measurements. One of the programs may, however, be too complicated/expensive for field applications. There is quite a significant difference among the cost of the selected programs. They range from $207.00 to $6,525.00.

By looking at the data in table 1, the following recommendations were made:

- To further investigate all of the selected programs through a laboratory program.
- Evaluate the possibility of implementing programs 1, 2, and 4 in the field and use program 3 in the more extensive investigations when the field programs indicate that a problem exists.

The laboratory evaluations of these programs are summarized in Task B.

4. TASK B: RECOMMENDATIONS AND IMPLEMENTATION PLAN.

This task involved the laboratory evaluation of the selected programs. The evaluation was aimed at answering the following two questions:

a. Is the test repeatable enough to be used in the field?
b. Is the test sensitive to small variations in the mixture components?

Based on these two questions, two programs were carried out: a repeatability study and a sensitivity study.

4.1 REPEATABILITY STUDY.

4.1.1 Field Density Measurement.

For this experiment one coal-tar source was used which was made of the following components:

1/2 quart coal tar
142 ml. water
283.5 gm sand

Six independent replicate samples were made and tested for their density following the procedure described in Task A, section 3.1.1. The following measurements were obtained:

Replicate	Density(lb/gal)	Mean	STD	COV (%)
1	11.473			
2	11.567			
3	11.613	11.567	0.05	0.4
4	11.578			
5	11.559			
6	11.610			

Where:

STD = Standard Deviation
COV = Coefficient of Variation (ratio of STD to mean times 100)

The above data show that the field density measurement test has excellent repeatability which is indicated by the extremely low STD and COV values. A COV value of less than 5 percent usually indicates excellent repeatability while a value higher than 15 percent indicates poor repeatability. In this case the test had COV of less than 1 percent which is excellent.

4.1.2 Percent Weight Wet Sand.

For this experiment one coal-tar source was used which was made up with the following components:

1/2 quart coal-tar
142 ml. water
283.5 gm sand

Four independent replicate samples were made and tested for their weight wet sand following the procedure described in Task A, section 3.1.2. The following measurements were obtained:

Replicate	Wt. Wet Sand (%)	Mean	STD	COV (%)
1	32.85			
2	33.45			
3	33.70	33.30	0.36	1.0
4	33.20			

The above data show that this test has excellent repeatability.

4.1.3 Mix Design Verification.

For this experiment one coal-tar source was used which was made of the following components:

1/2 quart coal-tar
142 ml. water
226.8 gm sand

Four independent replicate samples were made and tested for their percent solids, percent ash, percent sand, gallons of water, and pounds of sand per 100 gallons of sealer following the procedure described in Task A, section 3.1.3. The following measurements were obtained: $ESW_{fed} = 10.00$, $DSW_{fed} = 5.34$, and $AW_{fed} = 1.99$

Replicate	Solids (%)	Ash (%)	Sand (%)	Water (gal.)	Sand (lbs)
1	53.40	37.17	23.13	26.50	376.35
2	53.40	37.17	24.54	27.00	408.10
3	53.40	37.17	24.19	23.50	391.12
4	53.40	37.17	24.01	23.25	386.64
Mean	53.40	37.17	23.97	25.06	390.55
STD	0.00	0.00	0.60	1.96	13.23
COV	0.0	0.0	2.5	7.8	3.4

The above data indicate that the repeatability of the Mix Design Verification program is excellent in all measurements except for the measurement of water gallons/100 gallons of sealer which is still in the good repeatability range.

4.1.4 Field Fuel Resistance.

This test was conducted in the field using actual pavement sections. Therefore, a true repeatability experiment could not be conducted. In order to get an idea on the repeatability of the test, two tests were ran side by side on a new unsealed pavement section and the following data were obtained:

	Loss of Gasoline (inches)	
Time (min)	Section 1	Section 2
0	0.0	0.0
15	0.1	0.1
30	0.4	0.2
45	0.6	0.3
60	0.9	0.5
75	1.0	0.7
90	1.0	1.0

As indicated earlier, the above experiment is not a true repeatability test; however, it shows that a significant amount of gasoline will penetrate unsealed pavements within a 30-minute period. The measurements from the two sections are not very close at the various time intervals but they do indicate that the gasoline penetration is only delayed by 15 minutes.

4.2 SENSITIVITY STUDY.

The objective of this experiment was to evaluate the sensitivity of the testing program to variations in the components of the mixture. In other words, this experiment will evaluate the ability of the testing program to identify changes in the mix design as it is delivered to the job site.

4.2.1 Field Density Measurement

In this experiment both the water and the sand contents of the standard mix design were changed independently and simultaneously and the resulting densities were measured for each combination. The hypothesis tested here was whether the changes in the water and sand contents would significantly change the measured density. The original mix design was the same one used in the repeatability experiment. Three replicate samples were tested for each combination. Tables 2, 3, and 4 summarize the data for any increase in the water content, any increase in the sand content, and any simultaneous increases in both water and sand contents, respectively.

TABLE 2. IMPACT OF INCREASE IN WATER CONTENT ON THE MEASURED DENSITY

Increase in Water Content (%)	Field Density			
	Weight per Gallon (lb/gal)	Mean	STD	COV
10	11.454 11.470 11.415	11.446	0.028	0.24
20	11.240 11.260 11.389	11.296	0.081	0.72
30	11.122 11.210 11.185	11.173	0.046	0.41
40	11.177 11.253 11.188	11.206	0.041	0.37
50	11.077 11.276 11.169	11.174	0.10	0.89

TABLE 3. IMPACT OF INCREASE IN SAND CONTENT ON THE MEASURED DENSITY

Increase in Sand Content (%)	Field Density			
	Weight per Gallon (lb/gal)	Mean	STD	COV
10	11.393 11.544 11.565	11.401	0.094	0.82
20	11.765 11.885 11.825	11.825	0.060	0.51
30	11.890 11.982 11.987	11.953	0.055	0.46
40	11.953 12.017 12.143	12.038	0.097	0.81
50	12.013 12.066 12.243	12.107	0.12	0.99

TABLE 4. IMPACT OF SIMULTANEOUS INCREASE IN SAND AND WATER CONTENTS ON THE MEASURED DENSITY

Simultaneous Increase in Sand and Water Contents (%)	Field Density			
	Weight per Gallon (lb/gal)	Mean	STD	COV
10	11.435 11.409 11.480	11.441	0.036	0.31
20	11.469 11.505 11.590	11.521	0.062	0.54
30	11.425 11.544 11.684	11.551	0.130	1.13
40	11.646 12.626 12.609	12.294	0.561	4.56
50	12.825 12.790 12.985	12.867	0.104	0.81

The data indicate that the density measurement is highly repeatable under all combinations of test variables. However, the main objective here was to evaluate the ability of the density measurement to identify the changes that were introduced into the mixture. For this purpose, the Least Squares Means (LSM) statistical analysis was conducted. The LSM method checks to see if the various means are significantly different at a certain confidence level. The tested hypothesis was as follows:

> "If the means of any combination of two treatments, i.e., change in water, change in sand, or simultaneous changes, are equal, this indicates that the density measurement cannot sufficiently differentiate among the treatments. On the other hand, if the means of any combination of two treatments are different, this indicates that the density measurement can sufficiently differentiate among the treatments."

In this research, the LSM analysis was conducted at a 95 percent confidence level. The analysis shows the following:

- All the means of density measurements generated from the changes in water content (table 2) are statistically equal.

- All the means of density measurements generated from the changes in sand content (table 3) are statistically equal.

- All the means of density measurements generated from the simultaneous changes in water and sand contents (table 4) are statistically equal.

The above observations indicate that the density measurement program is highly repeatable but it cannot be effectively used to identify changes in the mixtures components as the mixtures are delivered to the job site.

4.2.2 Percent Weight Wet Sand.

In this experiment both the water and sand contents of the standard mix design were changed independently and simultaneously and the resulting wet sand weight was measured for each combination. The hypothesis to be tested here is whether the changes in the water and sand contents would significantly change the measured weight wet sand. The original mix design is the same one used in the repeatability experiment. Three replicate samples were tested for each combination. Tables 5, 6, and 7 summarize the data for increases in water content, increases in sand content, and simultaneous increases in both water and sand contents, respectively.

TABLE 5. IMPACT OF INCREASE IN WATER CONTENT ON THE MEASURED WEIGHT WET SAND

Increase in Water Content (%)	Weight Wet Sand			
	Percent Wet Sand (%)	Mean	STD	COV
10	32.10 32.55 32.85	32.50	0.38	1.1
20	31.55 31.60 31.40	31.52	0.10	0.3
30	30.15 30.60 31.15	30.63	0.50	1.6
40	31.70 31.45 31.50	31.55	0.13	0.4
50	32.20 32.25 31.90	32.12	0.19	0.6

TABLE 6. IMPACT OF INCREASE IN SAND CONTENT ON THE MEASURED WEIGHT WET SAND

Increase in Sand Content (%)	Weight Wet Sand			
	Percent Wet Sand (%)	Mean	STD	COV
10	35.05 34.70 34.85	34.87	0.18	0.5
20	39.15 39.20 38.90	39.08	0.16	0.4
30	41.74 39.60 41.15	40.83	1.11	2.7
40	41.75 43.00 42.80	42.52	0.67	1.6
50	44.75 44.45 44.25	44.48	0.25	0.6

TABLE 7. IMPACT OF SIMULTANEOUS INCREASE IN SAND AND WATER CONTENTS ON THE MEASURED WEIGHT WET SAND

Simultaneous Increase in Sand and Water Contents (%)	Weight Wet Sand			
	Percent Wet Sand (%)	Mean	STD	COV
10	35.90 36.55 36.60	36.35	0.39	1.1
20	38.05 38.00 37.90	37.98	0.08	0.2
30	38.95 38.90 39.25	39.03	0.19	0.49
40	40.60 39.00 41.25	40.28	1.16	2.9
50	41.05 42.70 42.40	42.05	0.88	2.1

The data indicate that the weight wet sand program is highly repeatable under all combinations of test variables. The ability of the weight wet sand program to sufficiently identify changes in the components of the mixture was evaluated using the same LSM technique as was described above. The analysis shows the following:

- All the means of weight wet sand measurements generated from the changes in water content (table 5) are statistically equal.

- All the means of weight wet sand measurements generated from the changes in sand content (table 6) are statistically different.

- All the means of weight wet sand measurements generated from the simultaneous changes in water and sand contents (table 7) are statistically different.

The above observations indicate that the weight wet sand measurement program is highly repeatable and it can be effectively used to identify changes in sand content and simultaneous changes in sand and water contents as the mixtures are delivered to the job site. A recommended implementation program is summarized in the recommendations section of this report.

4.2.3 Mix Design Verification.

In this experiment, both the water and sand contents of the standard mix design were changed independently and simultaneously and the resulting percent solid, percent ash, percent sand, water gallons, and sand pounds were measured for each combination. The hypothesis to be tested here is whether the changes in the water and sand contents would significantly change the measured parameters. The original mix design is the same one used in the repeatability experiment. Three replicate samples were tested for each combination. Table 8 summarizes the data for increases in water content, increases in sand content, and simultaneous increases in both water and sand contents.

TABLE 8. THE IMPACT OF CHANGES IN THE WATER AND SAND CONTENTS ON THE MIXTURE DESIGN VERIFICATION PARAMETERS

Mix	Changes	Solids (%)	Ash (%)	Sand (%)	Water (gal/100 gal)	Sand (lb/100 gal)
Standard	None	53.40	37.17	23.97	25.00	391.00
Increase in water (%)	25	53.40	37.17	18.94	30.00	299.00
	50	53.40	37.17	18.62	37.00	364.50
Increase in sand (%)	25	53.40	37.17	27.43	19.00	449.10
	50	53.40	37.17	31.89	22.00	568.10
Increase in water and sand (%)	25	53.40	37.17	26.41	31.50	463.81
	50	53.40	37.17	26.77	37.50	490.70

This program measures the actual quantities of water and sand per 100 gallons of the sealer; these numbers can be checked against the original values in the standard mix. For example when adding 25 percent more water to the original water of 25.00 gal/100 gal of sealer, the procedure identified it as 30.00 gal/100 gal of sealer which was 1.25 gallons less than what was actually added (31.25 gal). The following represents a summary of this comparison:

Water Added	Sand Added	Actual Water (gal)	Measured Water (gal)	Difference (%)
none	none	25.00	25.00	0.0
none	25%	25.00	19.00	24.0
none	50%	25.00	22.00	12.0
25%	none	31.25	30.00	4.0
25%	25%	31.25	31.50	0.8
50%	none	37.50	37.00	1.3
50%	50%	37.50	37.50	0.0

Water Added	Sand Added	Actual Sand (gal)	Measured Sand (gal)	Difference (%)
none	none	391.00	391.00	0.0
25%	none	391.00	299.00	23.5
50%	none	391.00	364.50	6.8
none	25%	488.75	449.10	8.1
25%	25%	488.75	463.81	5.1
none	50%	586.50	568.10	3.1
50%	50%	586.50	490.70	16.1

The above data show that this program is capable of identifying changes in the quantities of added water or sand as long as the amount of materials has actually been changed. For example, if the amount of water is increased, the method can accurately identify the addition but if the amount of sand is increased, the method may give false changes in the amount of water. This is also true for the measured amount of sand. Therefore, this method is reliable to measure only one change at a time as follows:

- If the engineer suspects that additional water has been included, the method can be used to identify the additional water but not the amount of sand.

- If the engineer suspects that additional sand has been included, the method can be used to identify the additional sand but not the amount of water.

Due to the above limitations and the extensive processes involved in this program, it is recommended that it only be used as laboratory analysis if the other simpler field programs have indicated that a problem exists.

4.2.4 Field Fuel Resistance.

The evaluation of the field fuel resistance test was conducted in terms of measuring the fuel penetration and extent of damage on three different sections: (a) unsealed pavement, (b) one coat of sealer, and (c) two coats of sealer. The experiment checked the gasoline penetration every 15 minutes and the extent of damage for test durations of 30, 60, 90, 120, and 150 minutes. In order to check the extent of damage at these test durations, it was necessary to test new sections for each test duration. Tables 9 through 13 summarize the data from this experiment.

TABLE 9. GASOLINE PENETRATION AND EXTENT OF DAMAGE FOR A 30-MINUTE DURATION

	Gasoline Penetration (inch)		
Time (min.)	Unsealed	One Coat	Two Coats
0	0	0	0
15	0.1	0	0
30	0.4	0.1	0
Damage	Severe	None	None

TABLE 10. GASOLINE PENETRATION AND EXTENT OF DAMAGE FOR A 60-MINUTE DURATION

	Gasoline Penetration (inch)		
Time (min.)	Unsealed	One Coat	Two Coats
0	0	0	0
15	0.1	0	0
30	0.4	0.1	0
45	0.6	0.1	0
60	0.9	0.1	0
Damage	Severe	Little	None

TABLE 11. GASOLINE PENETRATION AND EXTENT OF DAMAGE FOR A 90-MINUTE DURATION

Time (min.)	Gasoline Penetration (inch)		
	Unsealed	One Coat	Two Coats
0	0	0	0
15	0.1	0	0
30	0.4	0.1	0
45	0.6	0.1	0
60	0.9	0.1	0.1
75	1.0	0.1	0.1
90	1.0	0.2	0.1
Damage	Severe	Little	None

TABLE 12. GASOLINE PENETRATION AND EXTENT OF DAMAGE FOR A 120-MINUTE DURATION

Time (min.)	Gasoline Penetration (inch)		
	Unsealed	One Coat	Two Coats
0	0	0	0
15	0.1	0	0
30	0.4	0.1	0
45	0.6	0.1	0
60	0.9	0.1	0.1
75	1.0	0.1	0.1
90	1.0	0.1	0.1
105	1.0	0.2	0.1
120	1.0	0.2	0.1
Damage	Severe	Noticeable	Little

TABLE 13. GASOLINE PENETRATION AND EXTENT OF DAMAGE FOR A 150-MINUTE DURATION

Time (min.)	Gasoline Penetration (inch)		
	Unsealed	One Coat	Two Coats
0	0	0	0
15	0.1	0	0
30	0.4	0.1	0
45	0.6	0.1	0
60	0.9	0.1	0.1
75	1.0	0.1	0.1
90	1.0	0.1	0.1
105	1.0	0.1	0.1
120	1.0	0.2	0.1
135	1.0	0.2	0.1
150	1.0	0.2	0.1
Damage	Severe	Noticeable	Little

The data in tables 9 through 13 indicate that the fuel resistance test is highly sensitive to field conditions. It shows a significant difference between the unsealed and sealed sections and even among the two sealed sections. It clearly indicates that gasoline will penetrate and severely damage an unsealed section within 30 minutes of the start of the test while it will not penetrate nor damage a sealed section.

5. SUMMARY AND RECOMMENDATIONS.

The overall objectives of this research project were to identify and evaluate the available field QA/QC programs for coal-tar emulsions. The study identified four existing programs and conducted an extensive laboratory experiment to evaluate these programs. Based on the results of the laboratory experiment, the following recommendations can be made:

- The density measurement program has proven to be highly repeatable but it is not sensitive enough to identify changes in the mixtures components as it is delivered to the job site. Therefore, the density measurement program is not recommended to be used in a QA/QC program.

- The weight wet sand measurement program has proven to be highly repeatable and sensitive to changes in the sand content and simultaneous changes in sand and water contents. However, it is not sensitive to changes in the water content alone. This indicates that the change in sand content is the most significant contributor to the changes in the weight wet sand measurement. Therefore, it is recommended that the weight wet sand program be used in a QA/QC program to identify changes in sand contents in field mixtures. The relationship presented in figure 2 can be used as the guiding criterion for this program. The following procedure is recommended:

  - Provide the weight wet sand as part of the mix design information as WWS_{mix}.

  - Obtain a sample from the delivery truck on the job site and measure the weight wet sand of the field mixture as WWS_{field}.

  - Calculate the percent change in the weight wet sand as follows:

$$\text{Percent Change} = \frac{(WWS_{field} - WWS_{mix}) \times 100}{WWS_{mix}}$$

  - Use this value on the x-axis of the relationship in figure 2 to estimate the additional quantity of sand that was added to the mixture.

  - If the additional sand is less than five percent, do not take any action. If the additional sand is five percent or higher recommend the use of the mix verification program to be conducted in the laboratory.

- The mix verification program has proven to be highly repeatable and sensitive to changes in the mixtures components but it is relatively expensive and complex to be used in the field on a routine basis. Therefore, it is recommended that the mix verification program be used as final step in a conflict resolution situation. In other words, the weight wet sand and the field fuel resistance tests should be used to identify problems in the field while the mix verification program be used in the laboratory in support of the final decision making process.

- Based on the data from this experiment, it is recommended that the field fuel resistance test be adapted for the FAA specifications as described in the previous part of this report. The failure criteria should be considered as 0.2 in gasoline penetration and noticeable damage after a 30-minute period.

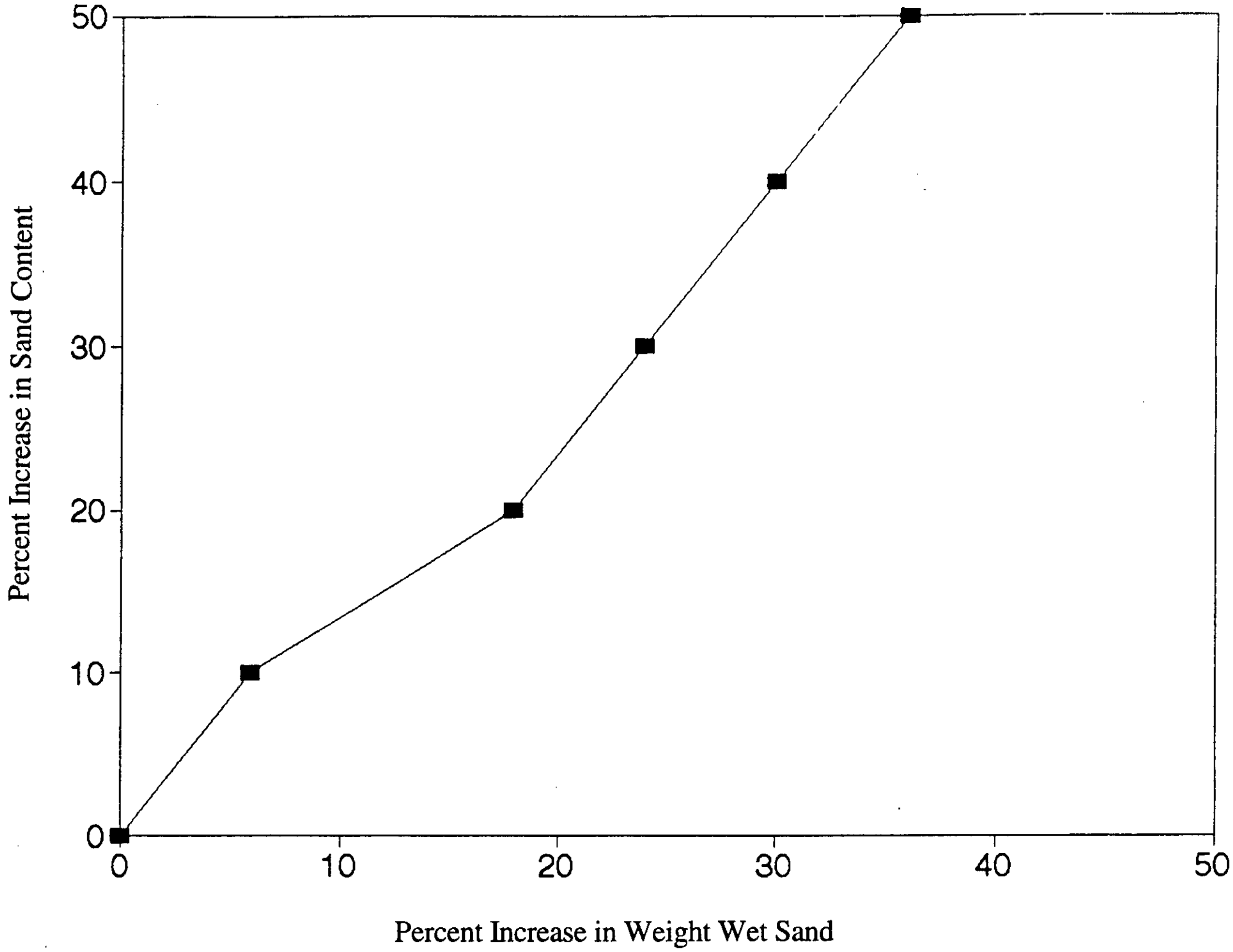

FIGURE 2. RELATIONSHIP BETWEEN CHANGES IN SAND CONTENT AND THE WET SAND WEIGHT

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