Bentonite Treatment for Fugitive Dust Control

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A laboratory and field evaluation was conducted of sodium montmorillonite clay (bentonite) as a dust palliative for limestone-surfaced secondary roads. It was postulated that the (negative) electrically charged surfaces of the clay particles could interact with the (positive) charged surfaces of the limestone and act as a bonding agent to agglomerate fine (− No. 200) particulates, and also to bond the fine particulates to larger (+ No. 200) limestone particles. Laboratory testing of limestone fines treated with soda-ash-dispersed bentonite indicated a significant improvement of compressive strength and slaking characteristics. Test roads were constructed in Dallas, Adair, and Tama counties in Iowa using bentonite treatment levels (by weight of aggregate) ranging from 0.5 to 9.0 percent. Quantitative and qualitative periodic evaluations of the roads were conducted with respect to dust generation, crust development, roughness, and braking characteristics. As the bentonite treatment level increased, dust generation decreased. About a 70 percent reduction can be achieved at 9 percent bentonite treatment. Wheelpath crust development is improved. Braking distance and braking handling characteristics under wet surface conditions do not appear to be adversely affected up to the 9 percent treatment level. The bentonite appears to be functioning as a bonding agent to bind small particulates to larger particles and is acting to agglomerate fine particles of limestone. This bonding capability appears recoverable over a wide range of environmental conditions. The bentonite appears to be able to interact with new applications of limestone maintenance material and maintains a dust reduction capability.

The Highway Division of the Iowa Department of Transportation has acted to address "fugitive dust" under research projects HR-151 (*1*) and HR-194 (*2*). This work used a number of different palliatives and proprietary products through laboratory screening and demonstration test sections. A common problem encountered is that many additives are good palliatives but are not cost-effective. The results of past work (*3*) indicate that most fugitive dust that is airborne past right-of-way limits is composed of the fine particulates of silt, clay, and colloidal-sized materials (minus 0.074 mm). Because of the size of these small particulates, the surface area per unit volume is very large. Since all aggregates exhibit a positively or negatively charged surface, the physical chemistry effects occurring between surfaces of fine particulates and chemical dust palliatives are significant. Past work (*1–3*) also indicates that for a dust palliative to be effective, the fine particulates must be flocculated, aggregated, or somehow physically bound to themselves or to larger particulates to prevent them from becoming airborne under traffic.

Results of a recent research project (*4*) indicate that significant dust reduction of fine crushed limestone particulates could be accomplished by a simple treatment with small amounts of bentonite (sodium montmorillonite). The bentonite was mixed with water using sodium carbonate as a dispersing and stabilizing agent and then topically applied. An application rate of 0.4 to 1.0 percent bentonite by weight of dry aggregate resulted in a dust reduction of 70 to 80 percent over un-

TABLE 1 Slaking and Strength Properties, Bentonite-Treated Alden Limestone Fines, Air Cured

	Untreated Control		Bentonite Treated	
Age, days	Slaking Time, minutes	Compressive Strength, kPa[1]	Slaking Time, minutes	Compressive Strength, kPa[1]
4	3	448	255	1240
9	4	345	185	1414
12	2	517	170	1379
14	2	414	180	1207

[1] 1 kPa = 0.145 lb/in^2

treated materials. The mechanism by which the dusting appears to have been reduced is significant. Surfaces of calcium-rich limestone particles are known to be positively charged. It had been postulated that introduction of a material of opposite or negative surface charge might bind the small particulates together. Sodium montmorillonitic clays were selected for use because they possess a negative surface charge. Scanning electron microscope and X-ray chemical dot-mapping of treated materials (*4*) revealed that fine dust particles were preferentially bonded to larger particles, and interparticle bonding was created between larger particles.

The results of this work indicate that bentonite treatment might be an effective dust palliative and stabilizing agent for limestone-surfaced secondary roads.

Laboratory Testing

To evaluate the potential strength of the interparticle physicochemical bonding of bentonite-treated limestone, laboratory testing was conducted to evaluate slaking and strength characteristics. A series of tests was initiated using various curing methods to simulate variations in field exposure of temperature and moisture. Limestone aggregates were obtained from the Alden quarry in northern Iowa. Cube samples 1 in. square were prepared using limestone fines passing the 0.042-mm (No. 40) sieve. The treatment level was a 10 percent solution by weight of bentonite (dispersed with soda ash) applied at a rate of 2 percent bentonite by weight of aggregate. Water was adjusted so the consistency of the mixes was uniform between mixes. Batches of 20 cubes were molded at a time.

Table 1 presents the results (average of at least two specimens) of slaking and strength tests on air-cured samples of untreated and treated limestone fines. Slaking tests were conducted by completely submerging the samples over an open-mesh support and measuring the time it took for the sample to collapse through the mesh. Comparison of the slaking data in Table 1 indicates that the soda-ash-dispersed bentonite samples extended slaking time to 40 to 90 times that of the untreated material. Slaking times typically decreased with age, probably because of loss of moisture from the samples. Compressive strength development using the soda ash as a dispersant was two to four times higher than for untreated material.

To evaluate the influence of temperature on the slaking and strength characteristics, samples were prepared and oven cured at 43.3°C (110°F) for 4 days. Samples were then removed from the oven and allowed to cure additional time both in air and in a desiccator. Table 2 presents the results, which are the average of at least two specimens. Again, fines treated with soda-ash-dispersed bentonite showed significant improvement in slaking and in compressive strength characteristics over the untreated fines. These data implied that bentonite was acting as a stabilizing agent for the fines, and hence might be expected to function as a dust palliative in the field.

Dallas County Test Road

Bentonite is commonly used as a drilling fluid because of its thixotropic properties. It becomes very slippery and sticky when mixed with water. One of the primary concerns on the field projects was the influence of bentonite treatment on braking and handling characteristics and general driving safety.

The test road in Dallas County had a relatively flat topography, few residences, and a traffic count of about 75 vehicles per day (VPD). Average gradation data of loose surfacing material indicated 8 percent passing the 0.074-mm (No. 200) sieve. Test sections were 320 m (1,050 ft) in length and included an untreated control section, 0.5 percent, 1.0 percent, and 1.5 percent bentonite-treated sections. Treatment levels were kept low because of concerns about braking characteristics.

Feed-trade bentonite (sodium montmorillonite) was used for the project. The soda ash (sodium carbonate) dispersing agent was obtained from a regional chemical supplier.

TABLE 2 Slaking and Strength Properties, Bentonite-Treated Limestone Fines, Initial 43.3°C Oven Cure for 4 Days

	Untreated Control		Bentonite Treated	
Added Cure	Slaking Time, minutes	Compressive Strength, kPa [1]	Slaking Time, minutes	Compressive Strength, kPa[1]
Air - 1 day	3	69	120	1103
Air - 5 days	3	103	40	1103
Desiccator - 1 day	3	103	120	1276
Desiccator - 5 days	3	103	65	1000

[1] 1 kPa = 0.145 lb/in^2

Two motor graders, operators, and a dump truck was supplied by Dallas County. Two truck-mounted spray distributors were equipped with 880-L (200-gal) per minute centrifugal circulating pumps and had a capacity of 11000 L (2,500 gal) each. The center spray bars were 8 ft long and equipped with eight No. 65 spray nozzles. Six-nozzle, 1.8-m (6-ft) hydraulic spray bars on each side allowed a spraying width selection of 2.4 m (8 ft), 4.3 m (14 ft), or 6.1 m (20 ft). Construction was completed on October 1, 1987.

Construction

For construction of the bentonite sections, all loose surfacing material was tight bladed and windrowed to one side. Several cross-sectional measurements were made of the windrow to estimate the amount of aggregate to be treated. The average of these data indicated approximately 193 t (190 tons) per mile of loose surfacing materials.

Bentonite solutions were field-mixed in the distributors in 5500-L (1,250-gal) batches at a 7.5 percent bentonite solution (by weight of water) concentration. The batch formula used 5500 L of water, 22.7 kg (50 lb) of soda ash, and 340 kg (750 lb) of bentonite. Field mixing was accomplished by connecting a 3-in.-diameter hose to the back of the distributor, which was then discharged into the top access port. The soda ash was slowly added by hand-pouring directly into the discharge stream, and was allowed to circulate approximately 10 min. The bags of bentonite (22.7 kg) were then slowly added to the discharge stream until 340 kg (750 lb) had been incorporated. The bentonite was allowed to circulate and mix for an additional 30 min. In general, field mixing and application of the bentonite solution proceeded very well with the conventional equipment.

For application the windrow was spread out to a width of approximately 2.4 m (8 ft) on half of the road. The distributor, using the center 2.4-m (8-ft) spray bar, applied about one-fourth of the solution in the first pass. Immediately behind the distributor, one patrol bladed the treated aggregate to a windrow in the center of the road. The following patrol spread the windrow to a width of 2.4 m (8 ft) on the opposite side of the road. The distributor then applied another one-fourth of the solution, and the process continued until the required amount of solution had been incorporated with the surfacing. Final blade mixing was accomplished with two passes of both patrols. One final pass was made to spread the material over the surface for traffic compaction. After construction, normal routine maintenance blading practice was followed for the duration of the project.

The medium bentonite-treated section (1.0 percent by dry weight of aggregate) required 11000 L (2,500 gal) of the 7.5 percent bentonite solution. The treated material was damp to wet. Treatment levels above 1.5 percent bentonite, using spray distribution methods, would have required drying between applications.

Field Testing

Field testing was conducted from October 1987 through August 1989 and consisted of fugitive dust tests (in and out of wheelpaths) using high-volume air sampling of dust generation under traffic and braking tests to evaluate the influence of treatment on stopping distances and handling characteristics.

Two high-volume stationary air samplers manufactured by General Metal Works were used for collecting dust. The high-volume sampler is based on gravimetric principles and capable of sampling large volumes of air for the collection of suspended particulate matter as small as 0.01 mm in diameter (*5*). Glass fiber filters were used for collection. For testing, both air samplers were placed in the center of each test section, one on each side of the road. The sampler blower motors were powered by a gas generator. Ten passes of a vehicle traveling at 64 to 72 kph (40 to 45 mph) were made between the samplers for each test. The filters with the collected dust were sealed in the field and returned to the laboratory for testing.

Testing was conducted periodically over a wide range of maintenance grading conditions, from well-developed wheelpaths to immediately after grading. Test results represent actual service conditions along with their inherent variability.

Figure 1 presents the results of wheelpath dust data over the project duration for the section with 1.5 percent bentonite. Dust generation is expressed as positive (increase in dust) or negative (decrease in dust) relative to the untreated control section. The control section is represented by the horizontal line at zero dust generation in Figure 1. The overall average of these data indicates about a 19 percent long-term (>2 seasons) reduction in dust generation. Dallas County applied 305 t (300 tons) of new limestone maintenance surfacing over the test road in August 1988, approximately 290 days after construction. This material was end-dumped and spread over the surface without blending. Test data indicate that the bentonite interacted with this new surfacing material and continued to function to reduce dust generation. Results shown in Figure 1 are typical for the treated sections. The 0.5 and 1.0 percent treatment levels reduced dust on the order of 5 percent over the project period. The total data set is presented in the final report for HR-297 (6).

The braking tests were accomplished using a half-ton pickup. The test was conducted by locking the brakes at a speed of 40 kph (25 mph). The braking distance was measured from the start of the skid mark to the center of the front wheels of the truck. Figure 2 shows the wheelpath braking test data for the Dallas County road. Ten tests were conducted under dry conditions; however, only four tests could be conducted under wet conditions. The average variation in results for the dry surface was considerably greater than that for the wet surface. This is believed to be due principally to the wide range of surfacing maintenance conditions under which tests were conducted as well as to the limited data set for the wet-surface tests. Although there are not enough data to be statistically significant, there did not appear to be any major differences in braking distance between the various test sections. The out-of-the-wheelpath tests show trends similar to the wheelpath tests for all bentonite treatment sections. These results indicated no apparent adverse effect on braking characteristics for the various treatments as compared with the untreated section.

Scanning Electron Microscopy

In order to determine if particle-to-particle bonding was taking place with bentonite treatment, samples of the

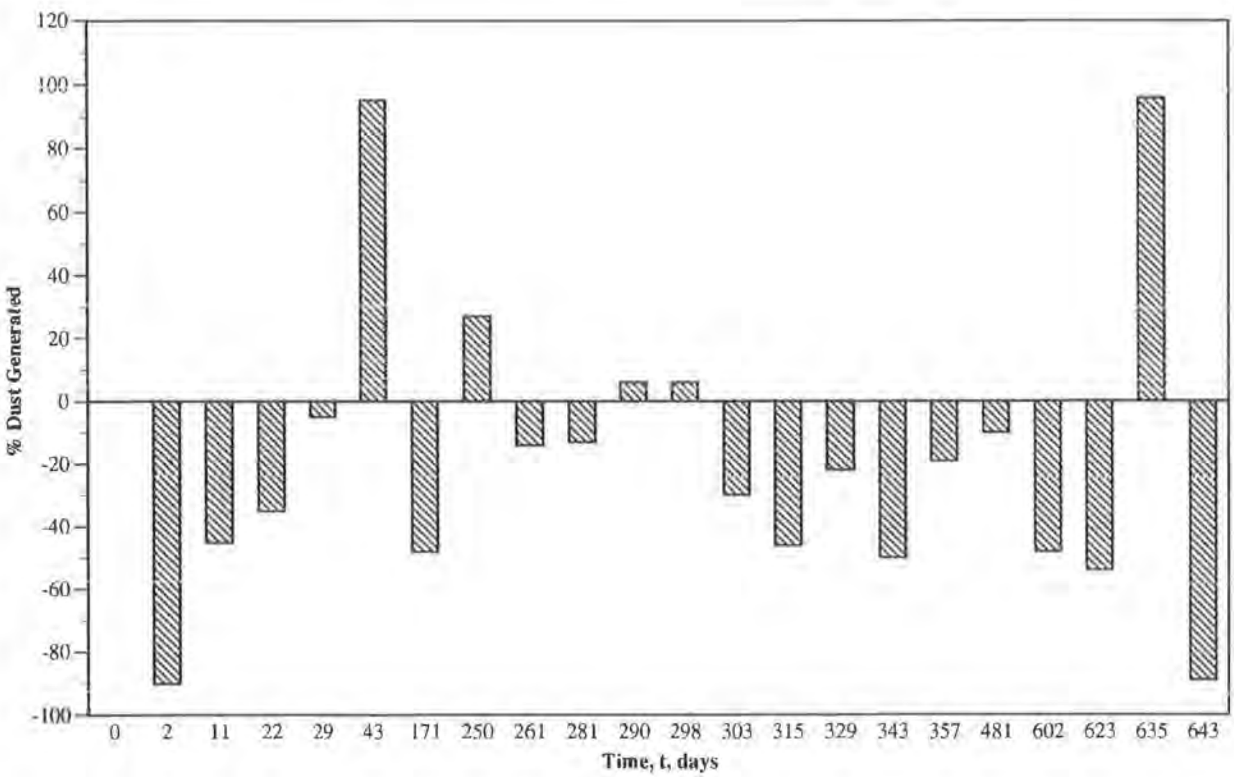

FIGURE 1 Dallas County test road dust generation for 1.5 percent bentonite treatment in wheelpaths.

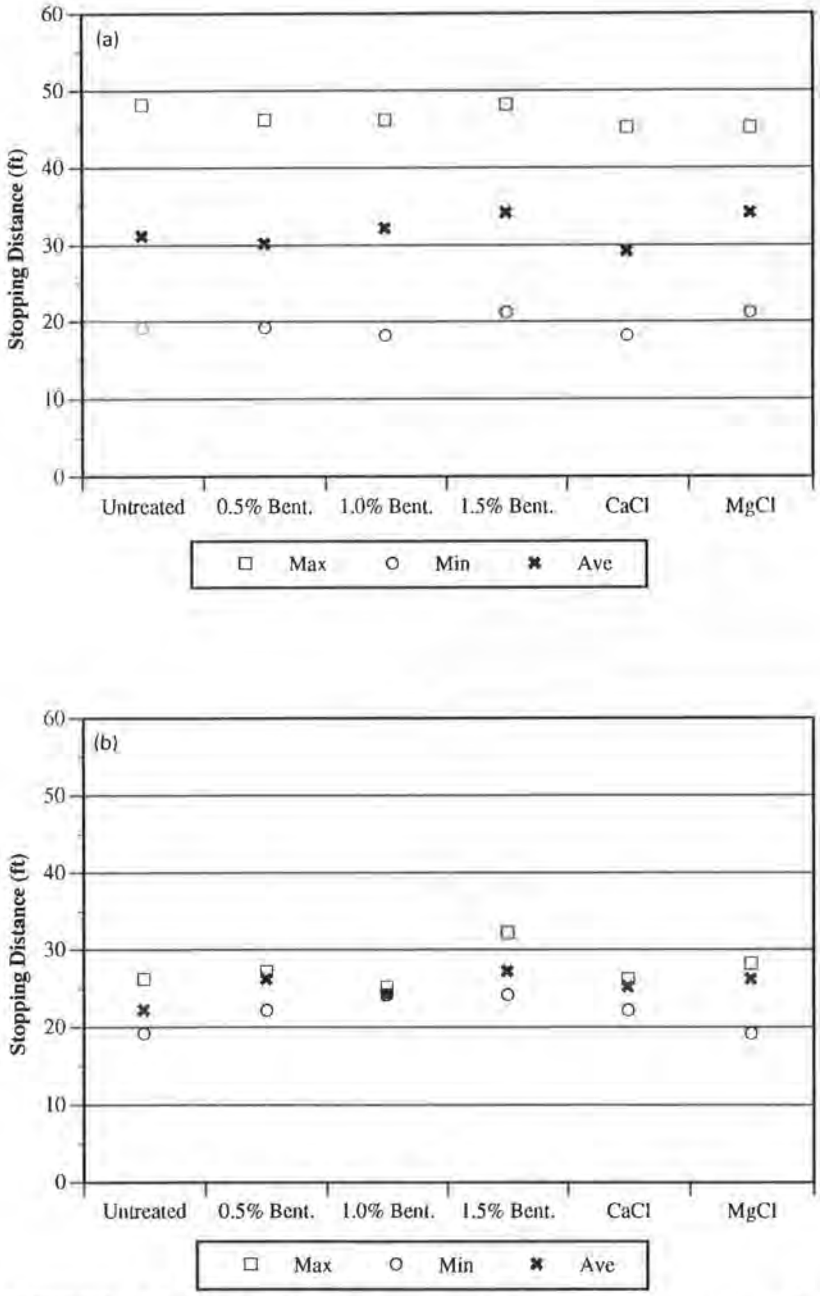

FIGURE 2 Wheelpath braking distance results for Dallas County test road on a dry surface (*a*) and on a wet surface (*b*).

material retained on the No. 50 sieve were mounted for scanning electron microscopy (SEM) analysis. Typical results are shown in Figure 3. Figure 3(*b*) is a threefold magnification of the agglomerated particle shown at the bottom center in (*a*). Scale bars are shown in the lower right corners. Particle-to-particle bonding and agglomeration of fines is evident. These results are typical of numerous SEM observations and study of samples from the No. 50, No. 200, and the minus No. 200 sieve fractions obtained at various periods throughout the project.

Adair County Test Road

Although the dust reductions observed in Dallas County were not dramatic, results were encouraging enough from the longevity of reduction and braking character-

(a)

(b)

FIGURE 3 SEM photographs of material retained on No. 50 sieve from 0.5 percent bentonite-treated section at 60 days after construction.

istics that an additional test road was constructed using up to 3.0 percent bentonite treatment in Adair County.

Based on the experience in Dallas County, the construction method was altered to incorporate higher percentages of bentonite treatment levels; therefore, a dry bentonite application method was developed. The Adair County test road traffic is about 80 VPD. Construction was completed in the first part of July 1989.

Construction

Before construction, the test road had been prepared by tight-blading the loose road surface material to a windrow on one side. Several cross-sectional measurements were taken and averaged for each section in order to determine the amount of bentonite needed for each treatment. The 22.7-kg (50-lb) bags of bentonite were then distributed along the measured and marked windrow in each test section and hand applied. The bentonite and the loose limestone surfacing were thoroughly dry-mixed by four passes of the two graders and finally spread in an 8-ft-wide layer on one side of the road.

The soda ash was added to the tank truck water at the rate of 9.1 kg (20 lb) per 2200 L (500 gal) of water and thoroughly mixed by the circulating pump. The water with soda ash was spray-applied to the 8-ft-wide strip of bentonite-treated limestone and simultaneously road-mixed by two motor graders working in tandem. Application of water with soda ash continued until a consistency of about a 7.6-cm (3-in.) slump concrete was achieved. After final mixing the material was spread uniformly over the road surface for traffic compaction. Normal periodic maintenance blading was resumed after construction.

Field Testing

Testing was conducted from July through November 1989. Dust data collected from this test road showed a significant increase in dust reduction at the higher percentages of bentonite treatment. Figure 4 shows the wheelpath dust data for the 3.0 percent bentonite-treated sections as compared with the untreated control section. An average dust reduction of about 41 percent was observed over the test period. The 1.5 percent treatment exhibited an average reduction of about 17 percent compared with the 19 percent reduction observed in Dallas County. The complete test data for the Adair test road are given in the final report on the project (6).

Results of the braking tests are shown in Figure 5 for the wheelpath testing. Fourteen tests were conducted on dry surfaces, and six tests were conducted on a wet surface. As with the Dallas County test road, results on the dry surface were more variable than those on the wet surface; however, no discernible trend appeared evident that would indicate an adverse effect on braking distance of bentonite treatment up to 3.0 percent.

Scanning Electron Microscopy

Several samples of material retained and passing the various fine sieve fractions were investigated using the SEM. Aggregation of particulates was routinely evident in bentonite-treated samples and not evident in un-

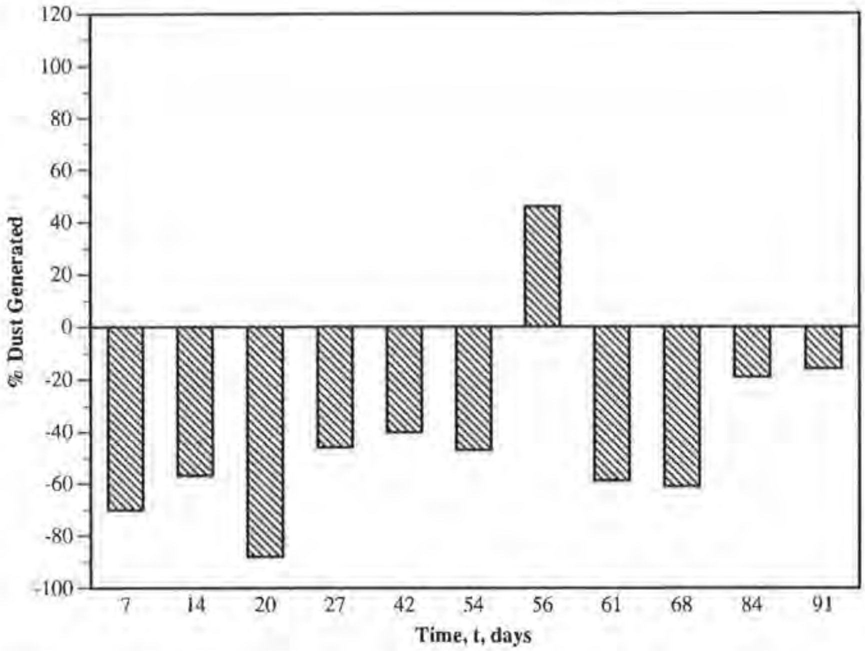

FIGURE 4 Adair County test road dust generation for 3.0 percent bentonite treatment.

treated samples, as was seen in the Dallas County photographs.

Tama County Test Road

Based on the results and experience of the Dallas and Adair county test roads, a project was initiated in Tama County that incorporated 3, 5, 7, and 9 percent bentonite treatment levels. Construction was by the dry application method used in Adair County, and proceeded rapidly. It was completed in 1 day under traffic.

Balling up or agglomeration of the bentonite was observed beginning with the 5 percent bentonite treatment section during the wet mixing process. This balling effect became more pronounced (but not drastic) as the treatment level increased, and was most apparent in the 9 percent section. Based on field observations and review of the lab data, the following changes in procedure are recommended for future construction: (*a*) use a soda ash solution concentrated (by weight of water) at one-tenth of the bentonite treatment percentage, and (*b*) alter the construction wet mixing procedure by saturating the dry bentonite-mixed surfacing material with soda ash solution before the first wet mixing pass of the patrol.

The fact that the sections treated with 7 and 9 percent did not get the bentonite as well dispersed throughout the material may have reduced its effectiveness.

Field Evaluation

With bentonite treatment, dust is reduced but is still being generated after treatment. Bentonite treatment does not achieve as dramatic results as chloride treatments, and the traveling public may not perceive a reduction. Therefore field testing on the Tama County test road consisted of qualitative evaluations by a panel.

Field testing consisted of qualitative evaluation of dust generation, crust development, and roughness and braking characteristics. Evaluations were conducted periodically and independently by a panel composed of personnel representing Marshall County, Tama County, the Iowa Department of Transportation, and Iowa State University (ISU).

An evaluation form developed by ISU was used by all the panelists for their observations. The form contained the following information: weather conditions (day of and day before evaluation); maintenance conditions; and surfacing material conditions, dry, damp, or wet. The panel evaluated the amount of dust generation for each bentonite-treated section compared with the control section and evaluated the crust development and roughness of each section. The dust generation was expressed as a percentage of the control, with the control having a value of 100 percent. The crust development and roughness were evaluated on a rating system from 0 to 5 with 0 being the worst and

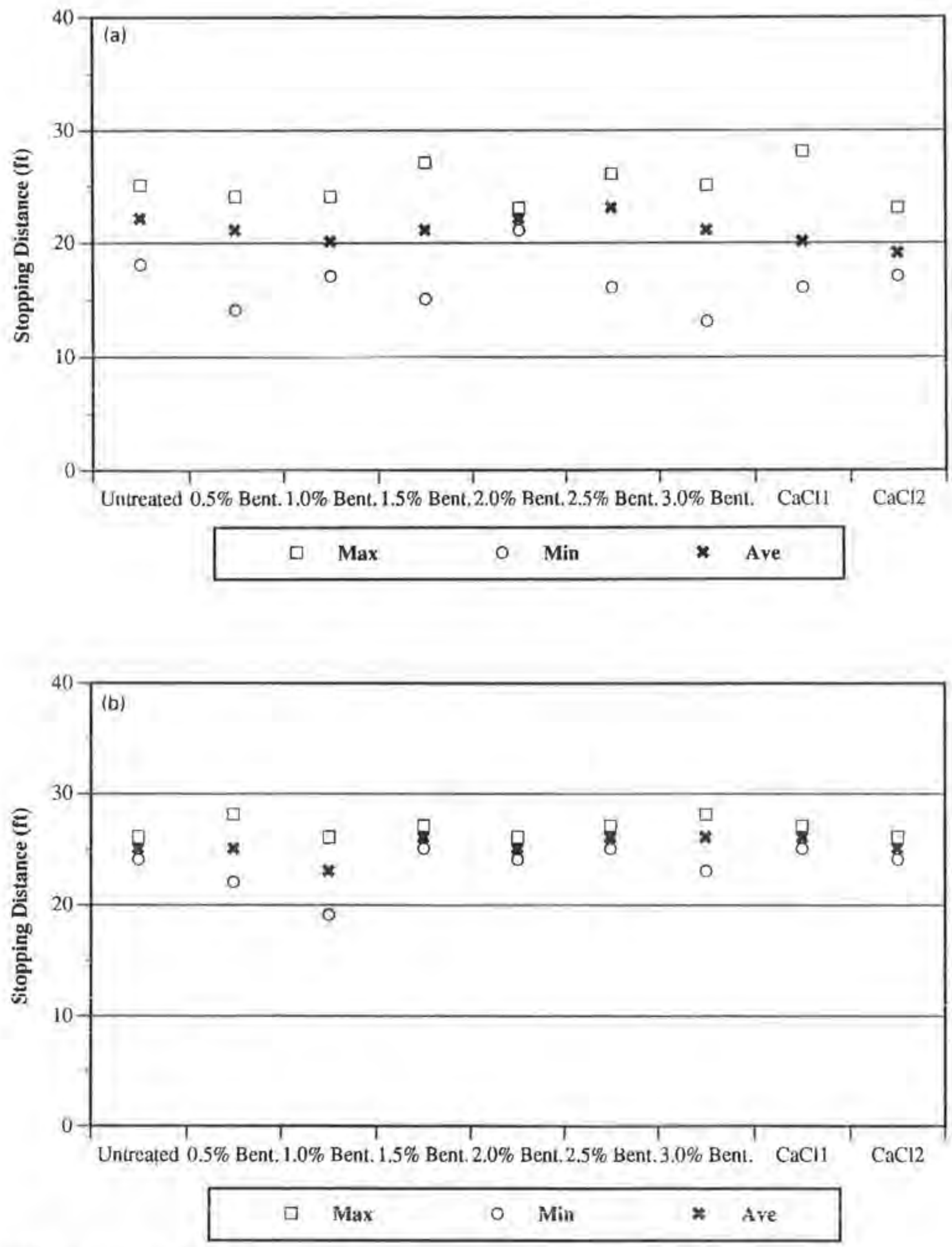

FIGURE 5 **Wheelpath braking distance results for Adair County test road on a dry surface (*a*) and on a wet surface (*b*).**

5 being the best rating. Results are shown in Table 3. Figures 6 and 7 show the data in graphical form.

The dust generation data indicated a relatively uniform standard deviation of plus or minus 11 percent at a 67 percent level of significance for all test sections. The data shown in Figure 6 must be viewed with this in mind. From Figure 6, the 3 percent bentonite treatment results in a dust reduction of about 45 percent, which compares roughly with the 41 percent quantitative wheelpath reduction observed for the same treatment level at the Adair County test road under the HR-297 project (*6*).

At a 9 percent treatment level, dust reduction is on the order of 70 percent. These qualitative data indicate that bentonite treatment is effective in reducing dust generation. It should be noted that the data for the 7 and 9 percent treatment may not reflect actual dust reduction capability because of inadequate dispersion of

TABLE 3 Evaluation Averages and Standard Deviations for Dry Surfacing Material Observations

Evaluation Category	Percent Bentonite	Average (n=19)	Std.Deviation (n=19)
Dust Generation	0	100	0
	3	55.0	10.9
	5	44.3	11.1
	7	39.1	10.4
	9	32.1	11.0
Crust Development	0	1.37	1.27
	3	2.21	1.36
	5	3.16	1.50
	7	3.11	1.45
	9	3.05	1.73
Roughness	0	3.74	1.33
	3	3.95	0.69
	5	3.95	0.83
	7	3.68	0.73
	9	3.21	1.10

the bentonite during the construction process. With a standard deviation of ±11 percent, differences between treated sections may be subject to question.

Crust development observation data given in Table 3 are shown graphically in Figure 7. These data indicate that the 3 percent treated section had somewhat better crust development than the control. The 5, 7, and 9 percent sections appeared to be relatively even, with values about two times better than the control. Good crust development would be expected to extend the life of the surfacing material. Again the standard deviation is about ±1.5, and differences may be questionable.

There was no clear trend evident with respect to roughness from Figure 7. All sections exhibited a rating from 3 to 4.

A major concern at the start of this project was the influence of high levels of bentonite treatment on braking characteristics and safety. Tama County and ISU personnel were at the site and conducted braking tests under wet to very wet conditions independently and at different times. There were no discernible differences in braking distance or handling characteristics during braking on any of the sections.

Scanning Electron Microscopy

Samples from the minus No. 200 sieve fraction from the control section and the 3 and 9 percent bentonite treatment sections were prepared for SEM micrographing. The bonding of the fines to the larger particulates was evident, as was the agglomeration of the fines.

Current Research

Field evaluation of the Tama County test road is ongoing. During the summer of 1993, a test road was constructed in Appanoose County incorporating bentonite treatment levels of up to 12 percent. Field evaluation there is also ongoing. Preliminary data indicate that braking and handling characteristics are not dastically affected at the 12 percent treatment level.

Economic Considerations

Table 4 summarizes construction cost breakdown data for materials and installation of bentonite treatment. Equipment and labor costs were the 1993 costs provided by the counties and assume construction of 1.6 km (1 mi) per day, which is conservative. Materials costs are FOB costs to the Des Moines, Iowa, area.

Cost of a 38 percent concentration calcium chloride treatment at an application rate of 0.95 L (0.25 gal) per square yard was approximately $1,600 per 1.6 km (1 mi) in 1993. In Iowa, a minimum of two applications per summer is normally required for dust control. This yields a minimum cost of about $3,200 per 1.6 km per year. The 9 percent bentonite treatment cost is about $1,750 per 1.6 km per year, assuming that the bentonite is effective for only one season. This is believed to be a conservative comparison since the longevity of dust reduction using bentonite has not yet been firmly established. Current data indicate that a single treatment acts to reduce dust over an extended time period (>2 seasons).

Conclusions

The results of this research indicate that bentonite treatment of limestone-surfaced secondary roads is a cost-effective dust reduction treatment. Data from the Dallas, Adair, and Tama county test roads indicate the following:

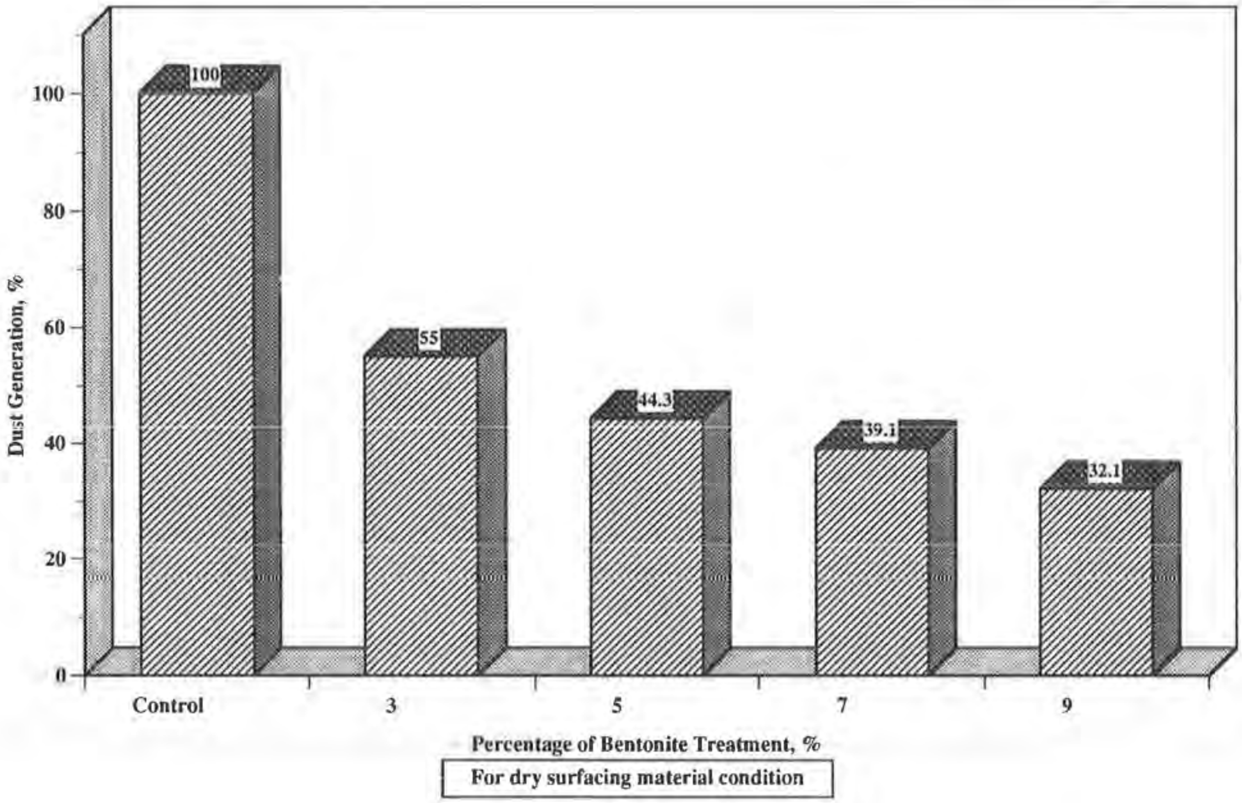

FIGURE 6 Average amount of dust generation for each level of bentonite as compared with control section.

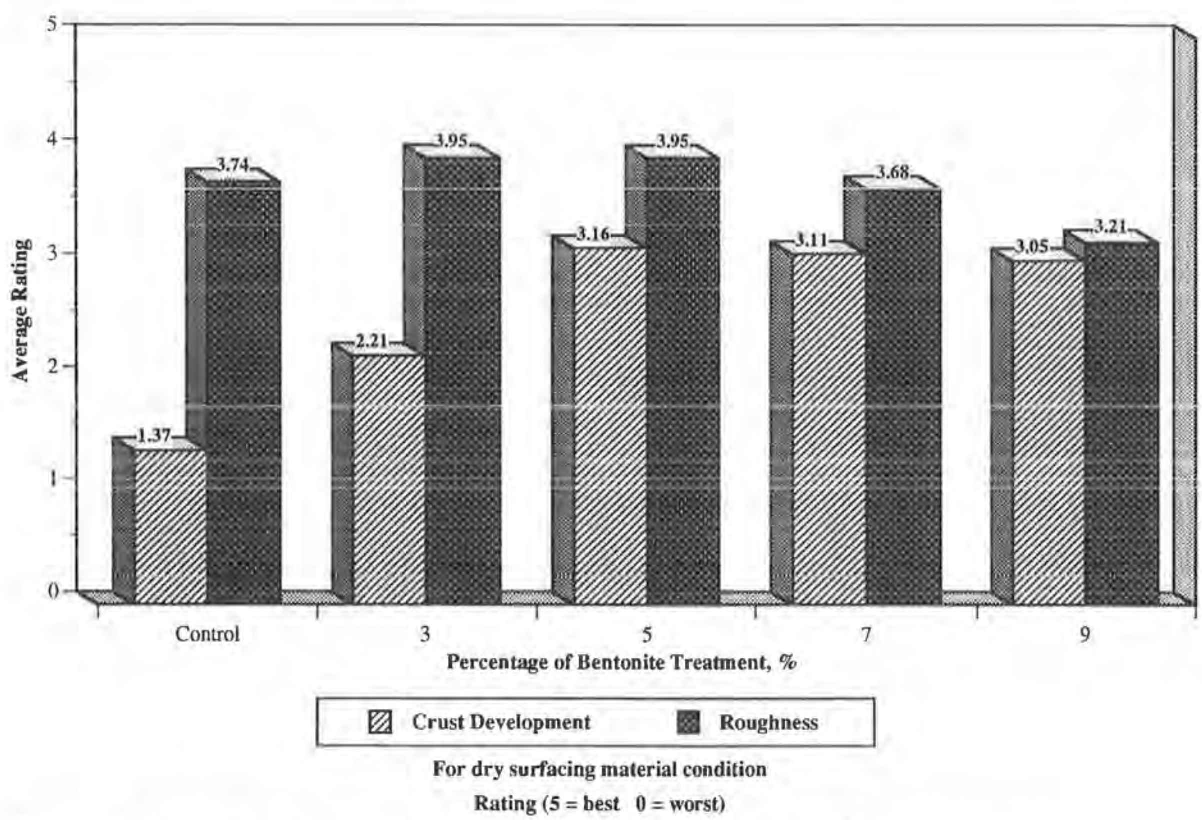

FIGURE 7 Average crust development and roughness ratings for each level of bentonite treatment.

TABLE 4 Breakdown of Construction Costs per 1.6 km, 1993 Cost Data

	3% Bentonite	5% Bentonite	7% Bentonite	9% Bentonite
	Cost in dollars			
Bentonite	300	450	795	1,375
Soda Ash	30	35	50	60
Water	35	40	50	70
Grader + operator	340	340	340	340
Tandem truck + operator	40	40	40	40
Water truck + operator	200	200	200	200
Actual Cost of Construction[a]	945	1,105	1,475	2,085
Normalized Cost [b]	990	1,230	1,480	1,740

[a]Estimated Amount of Limestone Present: 3% section ⇒ 111 t/mile (109 ton/mile)
5% section ⇒ 100 t/mile (98 ton/mile)
7% section ⇒ 126 t/mile (124 ton/mile)
9% section ⇒ 170 t/mile (167 ton/mile)

[b]Normalized Costs Based on a Typical Secondary Road Average of 127 t/mile (125 ton/mile) of Loose Limestone Surfacing Material.

- Bentonite treatment levels from 5 to 9 percent by weight of aggregate may provide cost-effective dust reductions ranging from about 50 to 70 percent, respectively;
- Dust reduction is believed to be accomplished primarily by the function of bentonite as a surface-active bonding agent to bind small particles to larger particles and agglomerate the fine (minus No. 200) particulates;
- The dust reduction mechanism appears recoverable from a wide range of environmental service conditions and remains effective for more than one season;
- The bentonite appears able to interact with limestone maintenance surfacing applied after treatment to maintain a dust reduction capability; and
- Braking and handling characteristics do not appear to be adversely affected up to the 9 percent treatment level.

Benefits

The use of bentonite as a dust reduction treatment appears to have the following benefits:

- It is low cost, readily available, naturally occurring, and environmentally sound;
- It is suitable for rapid construction under traffic using conventional equipment and county personnel;
- Normal county maintenance blading practices can be followed; and
- It displays long-term effectiveness.

A disadvantage of bentonite treatment is that it does not result in the same initial dramatic dust reduction as chloride treatment. Although dust is significantly reduced, it is still generated, and the traveling public may not perceive a reduction.

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