MECHANICAL ALTERATION OF THE TEXTURE OF OLD CONCRETE PAVEMENT WITH THE KLARCRETE MACHINE

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Experiments were performed with the British Klarcrete machine to determine its capability for removing the top layer of roadway to a depth of ⅛ to ¼ in. (3.175 to 6.35 mm) and, in so doing, to expose a fresh surface of highly fractured coarse aggregate to give a better skid resistance. In addition, experimentation was performed to determine whether the machine could be used as an efficient means of completely cleaning bridge decks of coal-tar epoxy prior to resealing. The machine employs 11 percussive hammers, mounted side by side at 2¼-in. (57.15-mm) intervals, that each strike the pavement approximately 1,500 blows/min and cut a maximum swath of approximately 4 ft. Each impact removes only a small amount of material but does not injure the surrounding pavement. The sole power requirement is a 600 ft^3 (17 m^3) per minute compressor producing 100 $lb/in.^2$ (689 kPa) pressure. The machine is self-propelled and its forward speed determines the depth of surface removed. In the experiments, the machine removed the surface layer of pavement and exposed a new surface of coarse aggregate with fractured jagged edges slightly raised above the surrounding mortar. It left no irregularities for water to pond and did not impair the riding quality of the road. Extensive skid testing proved that the skid resistance was raised significantly under specified conditions. The bridge cleaning experiment was successful, with the bridge being cleaned more efficiently, faster, and with less expense than by sandblasting.

•THE EXPERIMENTS reported here were conducted as part of an evaluation of available methods for increasing the harshness of texture of old concrete pavements. Included among the methods to be evaluated in the overall study are those that are presently used, such as grooving and sandblasting, but the real emphasis is to discover new and better methods of roughening the pavement. It probably is not necessary to recount the reasons for effort being spent in search of better ways of increasing the texture of concrete pavements. It will suffice to note that concrete pavements have been proved to approach a slippery condition when wet after 20 to 25 million vehicle passes (1) and that many concrete pavements recently put into service are approaching that accumulated volume. Long before this type of pavement becomes slippery as measured by conventional methods, the surface becomes smooth, and this, when coupled with the inability of portland cement concrete to allow water to penetrate the surface even under pressure, provides an ideal condition for hydroplaning under specified water, tire tread depth, and velocity conditions.

One avenue of investigation emphasized in the study was the mechanical alteration of pavements (2). It was contemplated that the exploration of this avenue would include a search for new machines that would physically remove part of the pavement surface through abrasion or other methods so as to leave a slightly uneven and unpolished new surface.

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In pursuing this avenue of investigation, it was learned that a British company, Klarcrete, Ltd., had developed a machine for treating concrete pavements, and it was obtained on a rental basis for a pilot study.

THE KLARCRETE MACHINE

The Klarcrete general-purpose concrete repair machine removes the pavement surface by employing 11 percussive hammers that operate independently, each striking the pavement approximately 1,500 blows/min. The machine operates on compressed air and requires at least a 600-ft^3 (17-m^3) per min compressor capable of producing 100 lb/in.^{2} (689 kPa) of compressed air. The hammers are 2¼ in. (57.2 mm) in diameter and 2¼ in. apart. They are mounted on a carriage that allows vertical movement and that in turn is attached to a transverse carriage that allows lateral movement. The lateral movement is necessary to get uniform removal of concrete over the width of operation. The width of cut can be varied from 4½ in. (114.3 mm) (diameter of cutting head plus space between cutting heads) to 49½ in. (1.3 m) in 4½-in. (114.3-mm) increments by adding or deleting individual cutting heads. Figure 1 shows the configuration of the cutting heads. The cutting heads, which require no lubrication and are free to rotate, break the concrete into small particles of a gradation not much larger than dust and cause no damage to the surrounding concrete. A person standing on the pavement beside the machine while it is in operation can notice the vibrations, but they are not great. The machine removes the surface by the number of impacts rather than the force of individual impacts. When the object is to remove the top surface of the concrete in a continuous sweep, the machine travels slowly forward under its own power. The depth of removal of concrete depends on the forward speed of the machine. A small pneumatic motor attached to the left rear wheel allows automatic operation and permits the towing of a compressor power source.

Figure 2 shows the Klarcrete machine being positioned for operation with the cutting heads in the raised position. Figure 3 shows the machine with the 11 percussive hammers in operation, and Figure 4 shows the machine with the compressor attached.

The control mechanisms for adjusting the speed of the machine, reversing its direction, and steering it are located on the tiller, which is attached to the front of the machine. Figure 5 shows a technician backing the machine by the controls and steering mechanism on the tiller. A second set of controls located on the right side of the machine regulates the speed (both transverse and vertical) and the pressure to the cutting head. A side view of the control box is shown in Figure 5.

The technical and physical aspects of the machine are given in Table 1.

PURPOSE

This project was initiated to determine the ability of the Klarcrete machine to remove the surface layer of concrete to an approximate depth of ¼ in. (6.35 mm) and, in so doing, to chip and fracture the aggregate (granite) to give fresh, sharp edges that protruded slightly above the surrounding mortar. This would provide improved skid resistance and help prevent hydroplaning. A second purpose, to determine whether the Klarcrete machine could be used to effectively clean bridges of hard-to-remove substances such as coal-tar epoxy, was added after the project was initiated. Cost data were developed to afford comparisons with other methods of texturing and bridge cleaning. Also of importance was the speed at which the machine accomplished its task, because the less time spent on high-volume highways, the better.

TEST SITES

After establishing the availability of the machine, a search was begun for suitable sites for the experiments.

Some important site characteristics needed for the experiments to remove the pavement surface were that (a) the portland cement concrete should be constructed with nonpolishing aggregate, (b) the road should carry high traffic volumes, and (c) the road must be old enough to have high accumulated volumes. In addition, it was desirable to have a site that had been tested and judged slippery, i.e., one with a skid number less

Figure 1. Configuration of cutting heads of the Klarcrete machine. (Two-headed arrow indicates that the heads move to right and left on a transverse carriage to cut area in between.)

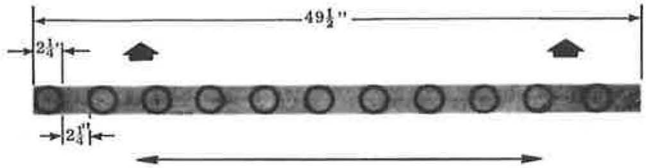


Figure 2. Klarcrete machine being positioned for operation.

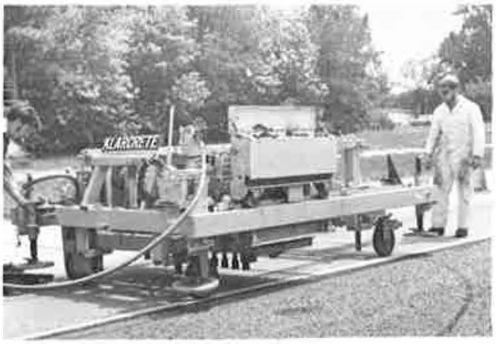


Figure 3. Klarcrete machine in operation.

Figure 4. Full view of Klarcrete machine and compressor.

Figure 5. Klarcrete machine being turned and positioned.

Table 1. Technical details of Klarcrete machine.

Item	Value
Overall length	14 ft (4.27 m)
Length without tiller	10 ft 4.5 in. (3.16 m)
Width	7 ft 6 in. (2.29 m)
Overall height	4 ft 6 in (1.37 m)
Weight	4,000 lb (1800 kg)
Power required, compressed air[a]	600 cfm at 100 psi (0.28 m^3/s at 689 kPa)
Cutting heads[b]	
Diameter	2¼ in. (57.15 mm)
Distance between heads	2¼ in. (57.15 mm)
Air consumption per head	30-35 cfm at 100 psi (0.014-0.017 m^3/s at 689 kPa)
Life	100 hours ± 25
Strokes per minute	≈ 1,500
Maximum cutting depth	4 in. (102 mm)
Accuracy	±⅛ in. (±3.18 mm)
Width of cut	4.5 to 49.5 in. (0.114 to 1.26 m)

[a]The Klarcrete machine is pneumatically and hydraulically operated and pneumatically controlled on a sequential system.
[b]There are 11 tungsten carbide cutting heads, composed of a motor and a head; each head can be controlled individually (except the first one). The cutting face is made up of 6 tips intersecting in the center of the head at 60 deg. Depth of the cut depends on forward speed of the machine.

Figure 6. Coal-tar epoxy on deck of northbound Meherrin River bridge.

than 40. The site selected was not the first choice, because the skid number was approximately 50 and the traffic volume was not extremely high (13,240 average daily traffic), but more desirable locations were not available for a variety of reasons.

The site is in the southbound direction of I-95 on the Emporia bypass in Greensville County, Virginia. The portland cement concrete pavement, constructed in 1959 of nonpolishing aggregate (granite), is 9 in. (0.23 m) thick and consists of 25-ft (7.6-m) and 50-ft (15-m) slabs. Although the site was not the best suited one for the experiment, it was entirely adequate for determining whether the machine would uniformly remove the surface and at the same time fracture the large aggregate so as to raise the skid values.

The bridges selected to test the machine's ability to clean coal-tar epoxy from the decks are over the Meherrin River in both the northbound and southbound directions of I-95, 0.4 mile (0.64 km) north of the pavement surface removal experiment.

EXPERIMENTS PERFORMED WITH THE KLARCRETE MACHINE

Removal of Road Surface

The first experiment performed with the Klarcrete machine was an operation called "mass area bush-hammering," a process by which the entire surface of the roadway is removed to a desired depth leaving exposed fresh, highly fractured aggregate slightly raised above the surrounding portland cement mortar. A ¼-mile (0.4-km) section of 24-ft (7.32-m) pavement was bush-hammered at the site, and ⅛ to ¼ in. (3.175 to 6.35 mm) of surface was removed. The operation was begun on May 14, 1973, and was completed May 24, 1973. The time of machine operation was 46 hours, 42 min. Each machine pass covered approximately 4 ft (1.22 m); six passes were required to treat the entire width of pavement. The total area treated was 30,934 ft^2 (2874 m^2), and the average area treated per hour was 680 ft^2 (63 m^2). The forward motion of the machine per hour was 170 ft (52 m).

Removal of Coal-Tar Epoxy From Bridge Decks

As previously noted, two bridges were selected for testing to determine the capabilities of the machine for bridge-deck cleaning. The bridges were covered with old, cracked, partially deteriorated coal-tar epoxy requiring removal before they were resealed with new epoxy. Considerable time, effort, and funds were spent the previous winter sandblasting the bridges in an effort to remove the epoxy, but with little success. Figure 6 is a view of one of the bridges showing the coal-tar epoxy after sandblasting. The right center cleared path was made by the Klarcrete machine.

Virginia highway department officials, after observing the machine in operation, wished to rent it in an attempt to remove the old epoxy from the bridges. The bridge cleaning operation, which was the same type of operation as bush-hammering (except for a different purpose and removal of different materials), began May 30 and was completed June 21. The time required to clean the southbound bridge was 36 hours, 50 min, for an average of 348 ft^2 (32 m^2) per hour. For the northbound bridge, the cleaning time was 49 hours, 54 min, for an average of 240 ft^2 (22 m^2) per hour. Progress on the northbound bridge was slower because the previous sandblasting on the southbound bridge had already removed some epoxy.

As may be seen, progress on both bridges was considerably slower than the 680 ft^2 per hour on the concrete road surface. This is explainable by comparing the different types of material that the machine was removing. The harder and more brittle a surface, the easier it is to fracture, and the more effective the operation of the Klarcrete machine becomes, because it functions by hammering the pavement surface into small particles. The road surface was hard and brittle and the machine operated efficiently on it, but the resilience of the coal-tar epoxy slowed operations on the bridges. In fact, it has been reported that attempts at removing bituminous overlays have not been very successful. In Virginia, however, the problem is not removing bituminous overlays from bridges, which can be done rather easily with a heater planer, but cleaning the bridges after the overlays have been removed.

PROBLEMS ENCOUNTERED DURING EXPERIMENT

Klarcrete Machine

With regard to maintenance, the Klarcrete machine performed creditably; minor problems did arise, however, in the form of broken air hoses. The average time for replacing a hose was 15 min. With sufficient hoses on hand, replacement was not a great problem, and downtime could be reduced by inspecting and replacing the hose where cracking occurs before operation. The cutting heads were replaced once during the experiments, but the time required was not prohibitive.

Compressor

The major equipment malfunction occurring during the entire experiment involved the compressor necessary to operate the machine. Four different compressors were used during the job, and each needed extensive repairs that necessitated long periods of downtime. The bush-hammering of the road surface required 9 working days, but the machine was in operation only 46 hours, 42 min. Over 90 percent of the downtime was attributable to compressor malfunction. For cleaning the southbound bridge, 36 hours, 50 min of machine time was necessary; however, the machine was inoperable 20 hours, 20 min because of compressor failure. In summary, malfunctioning of the compressors approximately doubled the time necessary for doing the job. A large compressor might do a better job, inasmuch as the air requirements of the Klarcrete machine are so great that the 600 cfm (0.28 m^3/s) compressors may have had difficulty sustaining production of the necessary air.

Regardless of the cause of compressor failure, the contractor should be required to guarantee a workable compressor because additional unwarranted time spent on a high-volume road increases the chances of accident to all involved, increases the cost for traffic control personnel (who often have other assigned tasks), and inconveniences the traveling public.

Noise and Air Pollution

Operation of the Klarcrete machine produced a noise level that was uncomfortable to persons in its immediate vicinity. For this reason, all machine operators should wear ear protection. No equipment was available for measuring machine noise, but, because no citizens complained, it must be assumed that the noise was absorbed by the environment to the degree that it was not a nuisance. It should be noted that, although a small town was nearby, the area is rural in nature; some means of muffling the noise might be necessary in a metropolitan area or for night work.

When the machine is operating on dry pavement, air pollution by dust can be great (Fig. 7). However, on wet pavement, no air pollution occurs. Figure 8 shows the machine operating after a downpour, but a water truck with a spray bar was employed at other times. In very hot weather, water evaporation is fast and the pavement has to be wetted often. The machine operates as well on wet pavement as on dry. A companion problem was that particles left by the machine had to be swept from the road with a mechanical sweeper that produced a dust cloud. The particles, nearly ¼ in. (6.35 mm) in depth, turned into a paste-like substance when sprinkled with water and could not be swept from the road. This problem was not solved at the test site and the particles were swept from the road while dry. A solution for this could be a vacuum type of street sweeper such as those used by some cities.

RESULTS OF EXPERIMENTS

Surface Alteration

The machine operated as it had been purported to do. In removing the entire surface to a depth of ⅛ to ¼ in., the riding quality of the road was not impaired and the noise level produced by vehicular traffic on the treated surface was not noticeably greater than that on the old surface. The freshly treated surface was regular and had no holes or indentations that would serve as traps for pools of water.

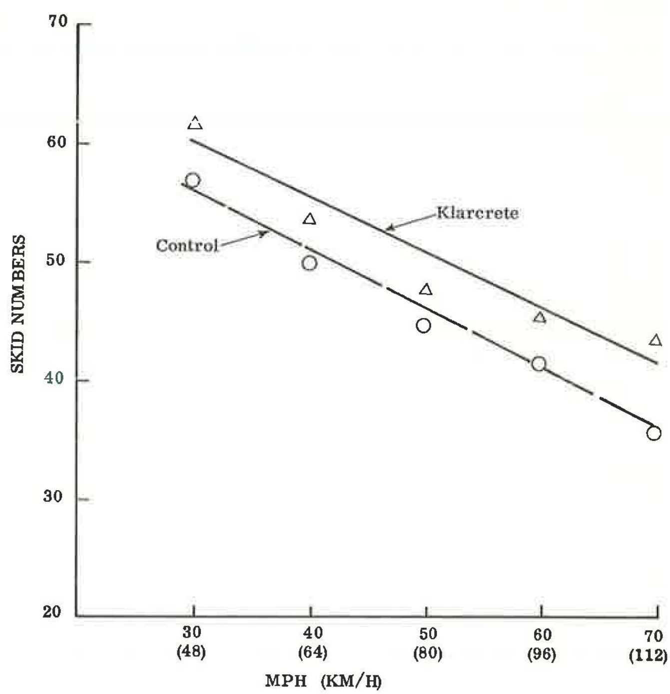
Figure 7. Dust produced by Klarcrete machine operating on dry pavement.

Figure 8. Klarcrete machine operating on wet pavement.

Figure 9. Wet pavement after treatment with Klarcrete machine. Note the ponding of water on the untreated portion.

Figure 10. The Virginia Highway Research Council's skid-resistance measurement vehicle.

Figure 11. Skid test results (traffic lane) with a new tire and 0.20-in. (0.508-mm) water film thickness.



The sharp surface of the granite aggregate protruded above the surrounding cement mortar to produce a texture that was coarse. The coarse texture allows considerable space for water to escape and also exposes a polish-resistant aggregate for contact with the tires of vehicles. Figure 9 shows the pavement after a heavy rain, when all of the pavement had been treated except the extreme right portion with the edge line marking.

Skid Tests

As previously mentioned, the purpose for removing the mortar and fracturing the large aggregate was twofold: (a) to provide a well-defined microtexture, particularly in the large granite aggregate, that was expected to improve the skid resistance of the pavement; and (b) to provide a surface macrotexture that would be less conducive to hydroplaning because it would facilitate the escape of water at the pavement-tire interface.

To determine if the expected improvements were realized, skid tests were performed with the Virginia Highway Research Council's skid trailer (Fig. 10) on the treated section and on a control section adjacent to it. The following tests were performed in both the traffic and passing lanes:

1. Conventional tests following ASTM Method E 274, made at 40 mph (64 km/hour) with 0.02-in. (0.508-mm) water film thickness. Tests were also made at 30, 50, 60, and 70 (48, 80, 96, and 112 km/hour) at the same water film thickness. These tests were performed with a new ASTM Standard E 249 tire.
2. The tests in 1 were repeated except that the ASTM Standard E 249 tire had been turned down to the point that it had no tread.
3. The tests in 1 were repeated except at a water thickness of 0.04 in. (1.016 mm).
4. The tests in 2 were repeated except at a water thickness of 0.04 in. (1.016 mm).

Figures 11 through 20 show the skid test data in graphic form. Each value is the average of five tests.

Figure 11 shows that the pavement not only had very good skid resistance before treatment when tested by ASTM Method E 274 but also had an acceptable skid number (SN) at 70 mph. Even so the Klarcrete treatment improved the skid number by about 4 units up through 60 mph and by about 8 units at 70 mph. If tests were performed at 40 mph only, it would be questionable if the increase in skid number from 50 to 54 would justify the expense of the treatment. However, the increase of 8 units, from 36 to 44, at 70 mph would justify the treatment if the site had a high wet-pavement accident history. Both curves in Figure 11 depict only a moderate loss in skid resistance with increased speed; this indicates no tendency toward hydroplaning.

Figure 12 shows results of tests using ASTM Method E 274 for the passing lane as opposed to the traffic lane. This lane had received less traffic, and it can be seen that no improvement was realized.

Results on the traffic lane with the bald tire are shown in Figure 13. The improvement in skid resistance is significant, even at the low speed of 30 mph, where the treatment caused an increase of 11 units. Since the curves are parallel and neither approaches zero, there is still no indication of absolute hydroplaning, although it is obvious that the channels in the pavement surface effectively provide for the escape of water when a bald tire is used, even when only a 0.02-in. (0.508-mm) water thickness is used.

In Figure 14, which shows results of the bald tire tests in the passing lane, two things should be noted. First, there is a smaller increase in the skid number as a result of treatment than there was in the traffic lane (8 units as compared to 11), and second, the skid number before treatment is about 6 units higher than that in the traffic lane before treatment. The latter fact indicates that the texture in the passing lane prior to treatment, although it was very fine and would probably be classified as microtexture, did provide for enough contact with the bald tire to generate skid values that would satisfy any minimum requirements.

All skid data reported graphically thus far resulted from tests performed with a

Figure 12. Skid test results (passing lane) with a new tire and 0.20-in. (0.508-mm) water film thickness.

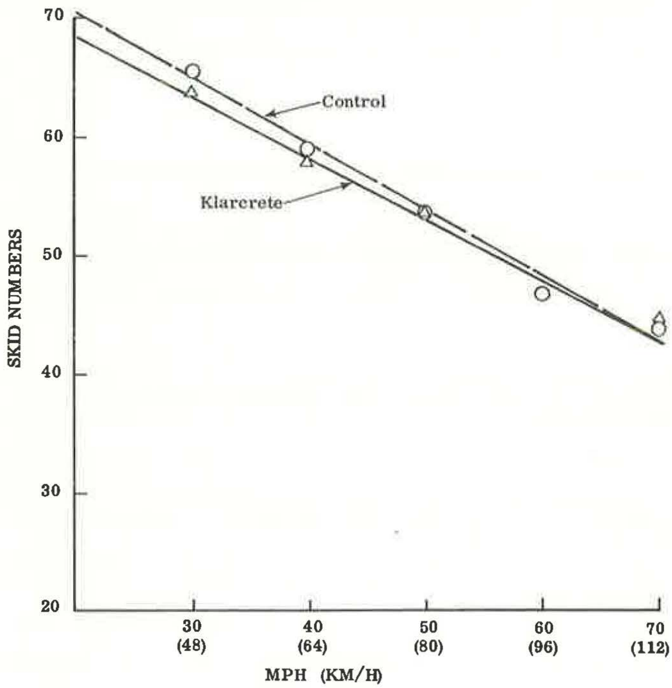


Figure 13. Skid test results (traffic lane) with a bald tire and 0.02-in. (0.508-mm) water film thickness.

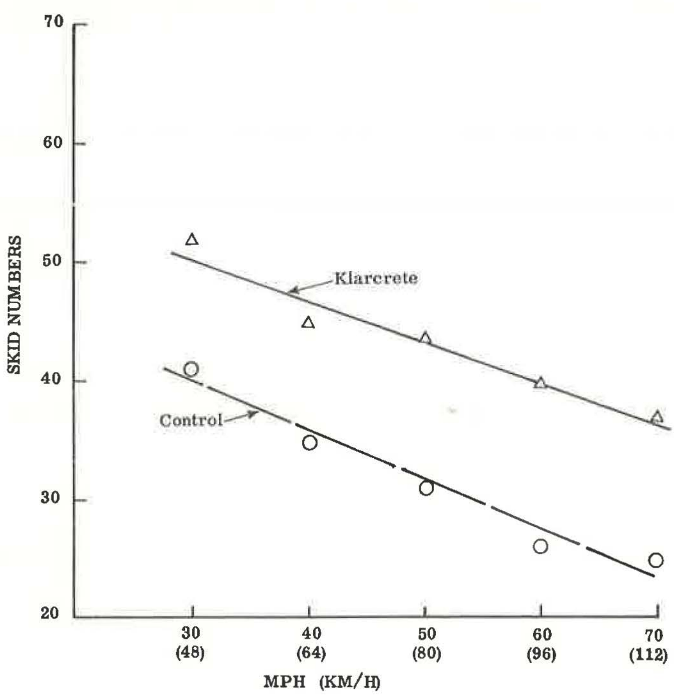


Figure 14. Skid test results (passing lane) with a bald tire and 0.02-in. (0.508-mm) water film thickness.

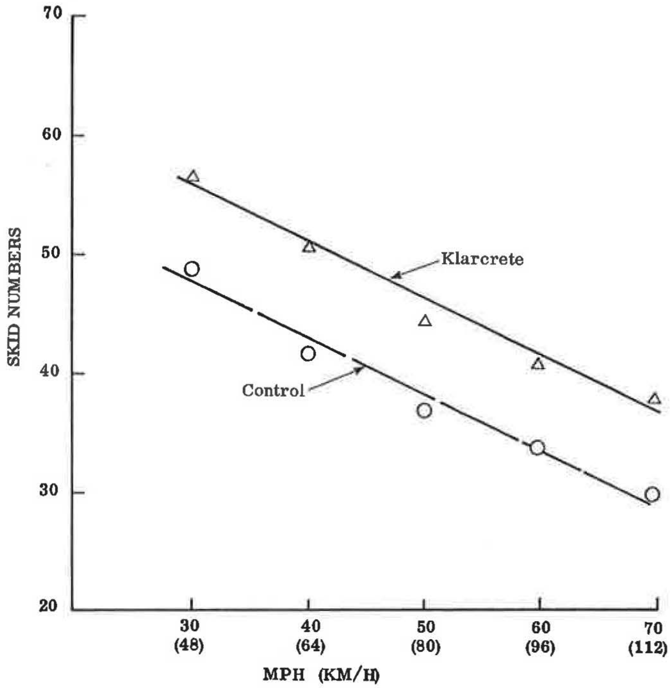
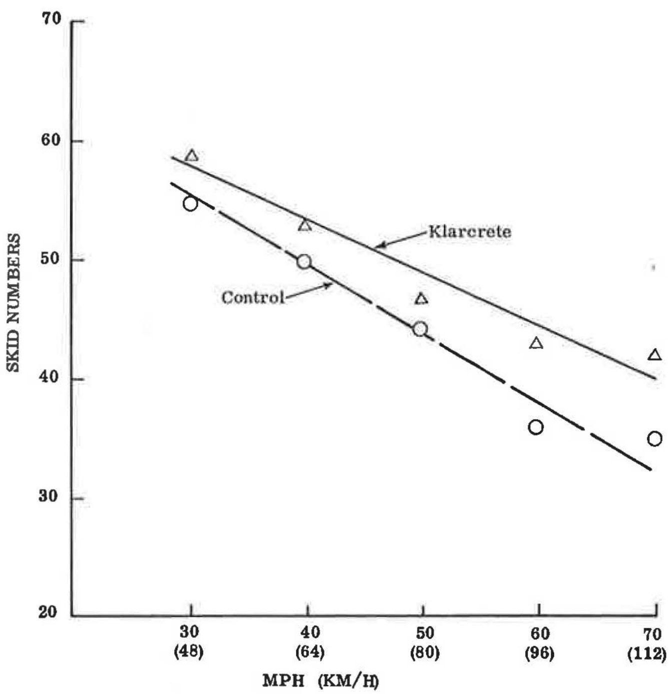


Figure 15. Skid test results (traffic lane) with a new tire and 0.04-in. (1.016 mm) water film thickness.



water film thickness of 0.02 in. The results in Figures 15, 16, 17, and 18 were obtained at a water film thickness of 0.04 in. (1.016 mm).

The values in Figure 15, obtained in the traffic lane with a new tire, are essentially the same as those shown in Figure 11, which were recorded in tests on half the water film thickness. This finding indicates that a film thickness of 0.04 in. is not enough to overtax a new ASTM tire and that, for realistic testing, the 0.02-in. film thickness prescribed by ASTM is sufficient.

Figure 16 shows the skid values obtained on the passing lane with the new test tire and a film thickness of 0.04 in. (Remember that in Figure 12, which showed tests with the same tire but half the amount of water, some values were higher for the untreated pavement than for the treated.) Figure 16 reveals the same phenomenon, which is accepted as insignificant or as a testing error because of the small amount of data. However, it could well be that a reduction in surface area under some conditions could reduce skid numbers.

Figure 17 differs from Figure 13 in that the tests were performed with a water film thickness of 0.04 in. The values for both the treated and untreated pavements with the increased water are lower by about 4 SN for the test speeds of 50, 60, and 70 mph. The decrease on the untreated surface was expected but that on the treated was not. This indicates that the greater water output resulted in a thicker film of water even on the rough-textured surface and that this additional water decreased the skid resistance at the higher speeds. This observation should be accepted as a possibility and not as a positive conclusion.

Figure 18 shows the data for the passing lane tests with bald tires and 0.04-in. water film thickness. Again there was a decrease in skid resistance on both the treated and untreated surfaces as compared to the results with 0.02 in. of water, but the decrease did not occur until the test speed reached 70 mph.

Figures 19 and 20 show data for 70-mph tests with 0.04 in. of water and six tire conditions ranging from new to bald. The values in Figure 19 are for the traffic lane and those in Figure 20 for the passing lane. These data clearly show that tread depth has no effect on the ASTM Standard E 249 tire until it reduces to less than $^3/_{32}$-in. (2.4-mm) tread depth for water depths as great as 0.04 in. In addition, if the 0.04-in. water depth can be accepted as representative of the films produced by many rains, the data suggest that a $^3/_{32}$-in. tread depth is sufficient for most wet-weather driving conditions.

Summary of Results of Skid Tests

As a result of the treatment, the skid resistance was raised in most cases; the exceptions are the test results from the passing lane when new tires were used. The absence of improvement in these cases is credited to the high skid resistance of the pavement before treatment and the drainage characteristics of the test tire. The improvements realized are a result of increased surface texture harshness, particularly on the large aggregate, and better provisions for drainage, especially for the bald tire.

Before testing, it was felt there was a possibility that the before and after tests using a bald tire, 0.04-in. water film thickness, and a test speed of 70 mph would demonstrate that the Klarcrete treatment would make the pavement less conducive to hydroplaning by providing a macrotexture that would facilitate the escape of water at the pavement-tire interface. However, although there is a tremendous difference between the curves for the $^3/_{32}$-in. tire tread depth and the bald tire (Figs. 19 and 20), in light of the slopes of the speed gradients of the curves (Figs. 11 through 18), the interpolation of rapid approach to absolute hydroplaning would be risky. Because no skid values were below 20, it is obvious that the test conditions were not conducive to hydroplaning. This does not imply that an automobile traveling at 70 mph with bald tires on the untreated section of this test site would not hydroplane, given certain water depth and driver handling conditions. Therefore, it can only be said that the test did not prove whether the treatment made the pavement less conducive to hydroplaning, but basic knowledge of the phenomenon coupled with the data would lead to a conclusion that the treatment will reduce the likelihood of hydroplaning.

Figure 16. Skid test results (passing lane) with a new tire and 0.04-in. (1.016-mm) water film thickness.

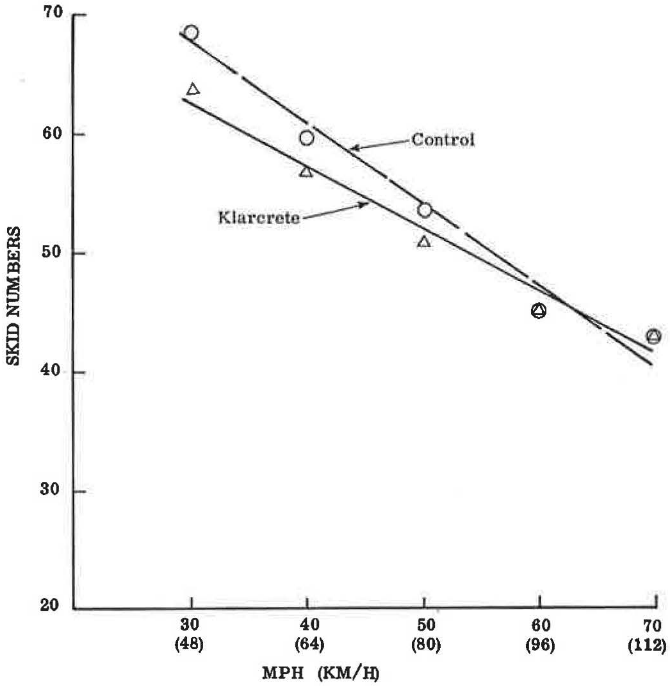


Figure 17. Skid test results (traffic lane) with a bald tire and 0.04-in. (1.016-mm) water film thickness.

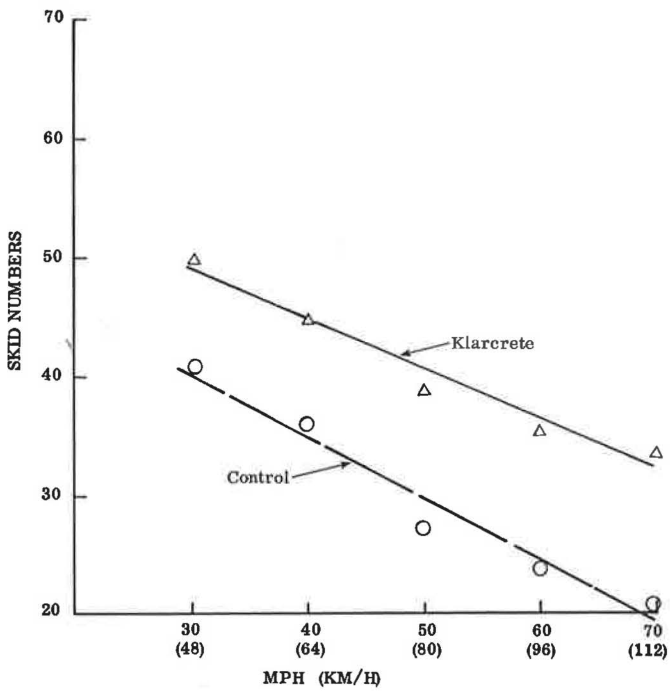


Figure 18. Skid test results (passing lane) with a bald tire and 0.04-in. (1.016-mm) water film thickness.

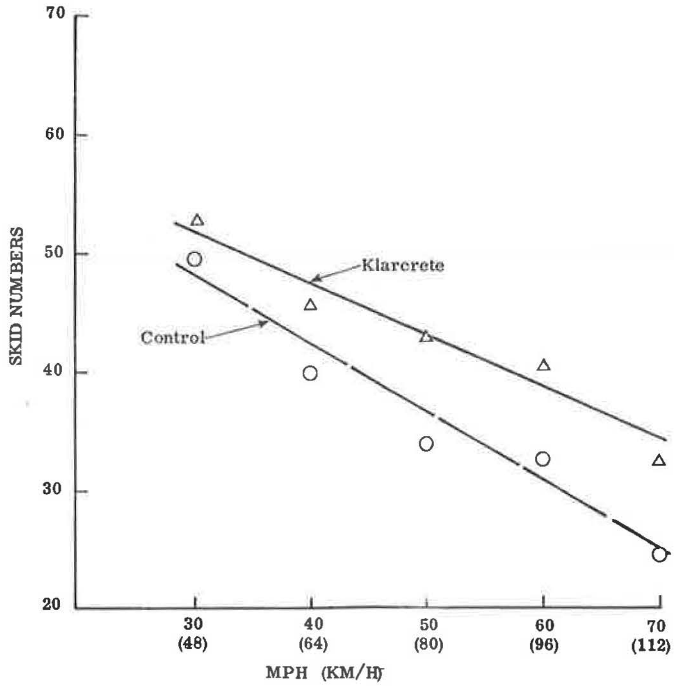


Figure 19. Effect of tire tread depth for tests (traffic lane) at 70 mph (112 km/hour) and 0.04-in. (1.016-mm) water film thickness.

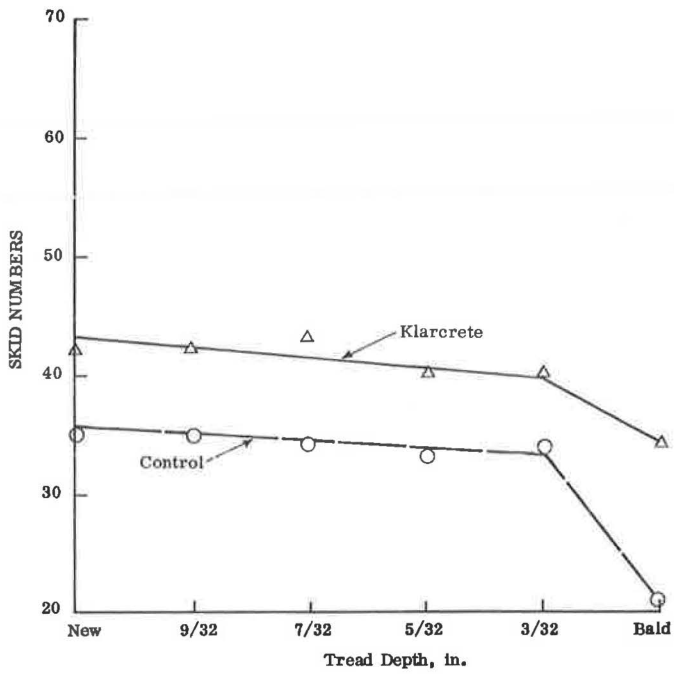


Figure 20. Effect of tire tread depth for tests (passing lane) at 70 mph (112 km/hour) and 0.04-in. (1.016-mm) water film thickness.

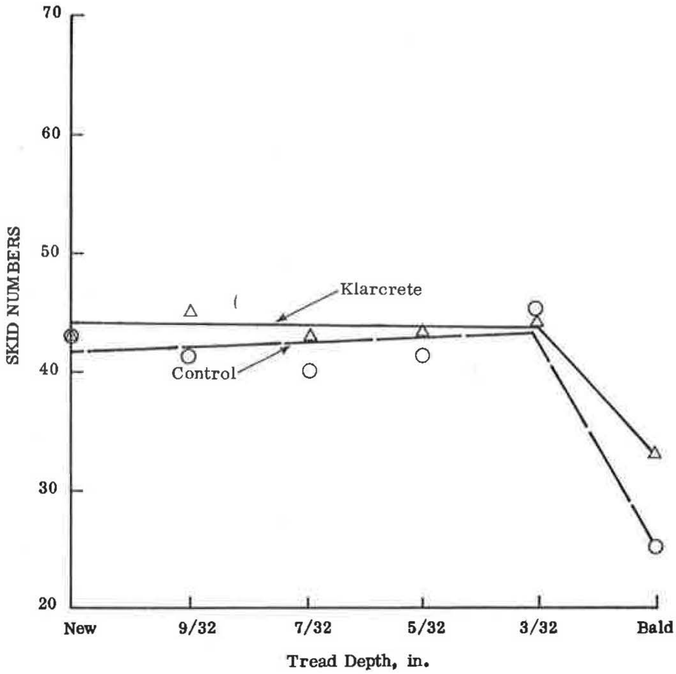
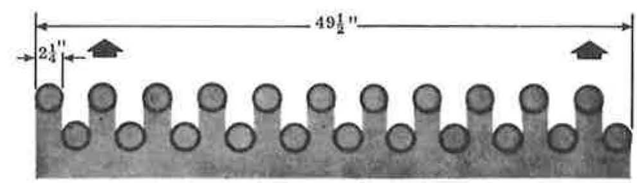


Figure 21. Long-range view of Klarcrete machine in operation on bridge deck.

Figure 22. The southbound bridge after cleaning.

Figure 23. Configuration of 22 cutting heads of new Klarcrete machine. (There will be no transverse motion of heads.)



Bridge Cleaning

Before sealing a bridge with epoxy it is necessary to completely clean the surface of foreign materials to give the epoxy a clean, sound surface to adhere to. Some bridge engineers feel it desirable to remove the surface down to the aggregate so that the fresh epoxy can adhere to it, the reason being that the surface mortar of an old bridge may have been weakened by deicing salts or other caustic agents to a degree that the new seal surface may scale off.

The Klarcrete machine did an excellent job of cleaning the bridge to a depth that exposed the coarse aggregate (Figs. 21, 22). It is faster and less expensive than sandblasting. From the results of this experiment it appears that the machine also holds real promise for cleaning bridges. Figure 21 shows the bridge cleaning operation, and the near white path directly behind the machine indicates the quality of work being performed by the machine. In some areas where the coal-tar epoxy was especially thick two passes were made. Figure 22 shows a portion of the bridge after cleaning was completed.

Cost

The cost of removing the surface and exposing the coarse aggregate from the approximately ¼-mile section of 24-ft pavement was $3,026.50, excluding the expense of traffic control. The total area, 30,934 ft^2 (2874 m^2), was treated at a cost of $0.10/$ft^2$ ($1.07/$m^2$). The cost of grooving in Virginia is about $0.20/$ft^2$ ($2.14/$m^2$). In comparison, the Klarcrete treatment costs about one-half as much. As previously noted, approximately 700 ft^2 (65 m^2)/hour of roadway were treated with the Klarcrete machine. This compares to about 1,000 ft^2 per hour (93 m^2 per hour) for grooving. Both the Klarcrete process and grooving provide means for water to escape from the pavement-tire interface, but the Klarcrete machine also exposes a new, skid-resistant surface.

A newer model Klarcrete machine, scheduled to be delivered to the United States in late fall or early winter of 1973, will double the rate of production and will, in fact, be considerably faster than grooving. The increase in production will be accomplished by having two rows of heads, with the second row offset 2¼ in. (57 mm) from the path of the first row. This will enable the machine to bush-hammer the 4-ft (1.2-m) swath without transverse movement of the heads and without increasing the compressed air requirements. Figure 23 shows the configuration of the heads of the new machine.

As noted earlier, the coal-tar epoxy on the bridges was more difficult to remove than the surface of the road, and in certain instances double passage with the machine was necessary. The total area on both bridges cleaned down to the coarse aggregate was 24,789 ft^2 (2302.9 m^2) and the cost was $5,187. This reduces to $0.21/$ft^2$ ($1.95/$m^2$). Because of the different sealant materials and thicknesses on different bridges, a comparison of this method with other bridge cleaning methods was not possible, but engineers from the Virginia Department of Highways state that the Klarcrete method was significantly less expensive and time-consuming than sandblasting.

CONCLUSIONS

The following conclusions were derived from the experimentation and subsequent skid tests.

1. The Klarcrete machine did an excellent job of removing the surface area to a depth of ⅛ to ¼ in. (3.175 to 6.35 mm) and was capable of removing a much greater depth.
2. After removal of the surface material, a coarse aggregate with sharp fractured surfaces was exposed above the surrounding cement mortar.
3. The cost of treating the roadway with the Klarcrete machine was approximately half of the cost that Virginia has had to pay for grooving.
4. The machine did an excellent job in cleaning the coal-tar epoxy from the bridges and was faster and cheaper than sandblasting.
5. In the experiment, approximately 90 percent of the downtime incurred was due to malfunctions of the compressors.

6. Although dust pollution can be a problem when the machine is operated on dry pavement, it is easily controlled by wetting the surface.

7. The riding quality of the pavement was not impaired by removing the surface and exposing the coarse aggregate.

8. The Klarcrete treatment provided a well-defined microtexture, particularly in the large granite aggregate, which made a substantial improvement in the skid resistance in the traffic lane.

9. Because of the existing high skid resistance in the passing lane, little improvement was indicated in the tests with new tires. The improvement with bald tires was not so great as was realized in the traffic lane.

10. The treatment facilitated the escape of water, but because of limitations on the test conditions, it was not proved that the hydroplaning potential was reduced. However, when these data are viewed in the light of basic knowledge, a judgment that the treatment would reduce the hydroplaning potential under prescribed conditions would seem valid.

11. The test lends validity to the selection of the 0.02-in. water film thickness by ASTM for its E 274 method, and the ASTM Standard E 249 tire seems to provide skid numbers without dropoff due to tread depth for treads as low as $^{3}/_{32}$ in. when ASTM Method E 274 is used.

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