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Bulletin 184

Development of New Non-Skid Road Surface Treatment

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The Development of Resinous Skid-Resistant Surfaces for Highways

H. S. NAGIN, Reliance Steel Products Company,
T. G. NOCK and C. V. WITTENWYLER, Shell Chemical Corporation

A new roadway surface treatment based on thermosetting epoxy resins is becoming of increasing interest to state highway departments. The attributes of this product, which is applied in approximately ¼-in. thicknesses, are (a) the simplicity with which it can be applied to concrete and bituminous roadways, (b) its ability to prolong highway life by smoothing out rough and cracked surfaces, (c) its ability to protect substrates from weather and chemicals, and (d) its ability to provide a skid-resistant surface.

The development of the coating has included an extensive experimental program involving both laboratory and field testing. The laboratory work consisted mainly of collecting physical data and developing test methods, application methods, and different formulations which would be of enough commercial interest to be included in the field testing program.

The field testing program, begun in 1954, has included installations on a heavily-traveled highway in the New York Metropolitan area. More than 100 variables in coating application techniques and composition have already been investigated by application in triplicate of test patches which covered more than a mile of highway. Of particular interest during these investigations were such properties as adhesion to concrete and bituminous materials; resistance to weather, de-icing chemicals, and other materials with which roadways may be in contact; resistance to thermal cycling, and wear resistance. Significant among the properties of the coating is an adhesion to portland cement concrete greater than the cohesive strength of the concrete.

A portable tester devised for determining adhesion of the coating shows promise as a tool for determining the strength of surface layers of concrete.

The test applications will continue to be observed and tested during the future for the purpose of developing data concerning their durability, but results of tests so far performed on the patches applied indicate that the new epoxy seal coat has great promise for use in critical areas.

● THE MOUNTING number of highway deaths, the rapidly growing property losses due in many cases to skidding accidents, and the increasing concentration of vehicles on the highways testify to the need for a skid-resistant roadway surface in many critical areas. An experimental composition is described here which has promise of accomplishing this purpose. It is applied in thin layers to provide an extremely high degree of skid resistance.

This new and unique surfacing material was developed for application on many types of highway surfaces to help eliminate the dangers of skidding. Although high skid resistance is a primary objective of this material, it also provides good wearing qualities and protection for the roadway from water, de-icing salts and freezing and thawing in winter weather.

It was pioneered six years ago by Reliance Steel Products Company of McKeesport, and, under the name Relcote (Registered Trade Name, Reliance Steel Products Co.), has been under development in a joint program between Reliance and Shell Chemical Corporation during the past two and a half years.

Basically, this new composition constitutes a third type of cement which will supplement the portland cement and bituminous cements that have long been used and proven in road building. This resinous cement is based on the epoxy resins in the form of a liquid polymer, which, on the addition of a curing agent or catalyst, sets up to a hard, tough adhesive solid. Unlike portland cement or bituminous materials, it has a high tensile strength, up to 8,000 psi. Unlike the bitumens, it has no flow even under heavy loads and at high temperatures. It combines the best wearing properties of the conventional cements with outstanding resistance to water, de-icing salts, and severe weather conditions. At the present time the base resin is relatively expensive; hence, except for special purposes, its use will probably be limited for some time to application in relatively thin layers ⅛ to ⅜ in. thick as a surfacing layer over existing portland cement or bituminous concrete roadways.

The need for a practical tractive surfacing material that can be applied to existing roadways is well known to highway engineers and is emphasized by the large areas of portland cement highways and bridges where the surfacing mortar has been worn or weathered away to expose aggregate which then becomes polished by traffic. If impregnated with oil drippings, these surfaces create serious skidding hazards when wet even for new tires. Under heavy traffic loads, similar hazardous conditions can sometimes be produced when the aggregate in bituminous concrete is either polished to a slippery state or is embedded by the familiar flushing action experienced at high ambient temperatures.

Resurfacing with either portland cement or bituminous concrete in such cases generally necessitates the use of layers of such considerable thickness as to require the raising of manholes, drains, and curbs on highways. On bridges, expansion joints and curbs are similarly affected; in some cases, an excessive dead weight load may be added when a thick resurfacing material is applied. The knowledge that most existing tractive surface treatments soon lost their initial skid resistance under heavy traffic loads and quite frequently exhibited poor adhesion in thin layers, especially to portland-cement concrete, led Reliance to undertake a study of synthetic resins for binders in this use.

The product which provides the key to this surfacing material is an entirely different class of resins introduced by Shell Chemical Corporation only eight years ago under the trade name EPON resins. Their wide use is attributable to an unusual combination of four properties: (a) excellent adhesion to most surfaces; (b) good chemical resistance; (c) toughness, enabling them to be hard without being brittle; and (d) rapid curing at normal temperatures. These properties, which have enabled the epoxy resins to become the standards of the paint, varnish, and plastics industries, also make them an ideal material for highway surfacing cements.

INITIAL DEVELOPMENT

The first interest of Reliance in developing a surfacing composition came as a result of many years of experience with light-weight concrete bridge floors. It had been observed that the major cause for deterioration of these floors was the cupping action caused by the unequal wear of concrete and steel which leaves hollows between the metal reinforcements where the concrete has worn away. To combat these effects a research program was begun to develop various materials and compositions which, when applied as surfacings, would decrease the water permeability of concrete and increase its wear resistance.

The first type of surfacing composition studied was essentially a concrete to which a polymer latex was added. In 1951 and 1952, Coatings Engineers, Inc., Pittsburgh, Pa., investigated the use of neoprene latex, Lumnite cement and mineral fillers. The neoprene-base concretes were generally unsatisfactory. In 1953 a contract was given to The Franklin Institute Research and Development Laboratories of Philadelphia, to study concretes containing polyvinyl acetate latex, using as a reference work done by Amagna, Mellor and Geist at the Massachusetts Institute of Technology. (1) However, an added feature of these concretes was that they were to be surfaced with carborundum grit to improve wear and skid resistance.

This research program yielded concretes that, when dry, were stronger and more resistant to wear, had lower water permeability, and showed better adhesion to base materials and greater skid resistance than conventional concretes. Unfortunately, although these concretes were impermeable to water, they were found to wear very rapidly

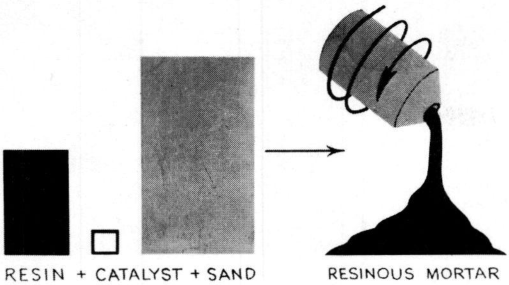

Figure 1. Materials and relative quantities used in resinous mortar.

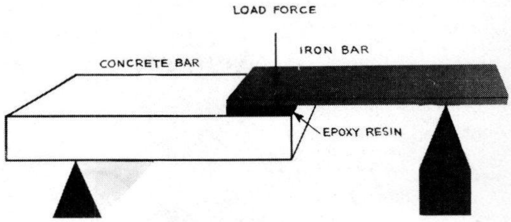

Figure 2. Bend test.

when wet. Experiments were continued with the polyvinyl acetate concretes using both crosslinking agents for the vinyl resin and a sodium methyl siliconate to try to reduce the water sensitivity. The results, while reasonably good, were not considered completely satisfactory.

Attempts to develop a suitable resin-base concrete were then abandoned and thinking next turned to mixtures of aggregates and thermosetting resins surfaced with carborundum grit because of the unusually good chemical resistance, high strengths, and adhesion to base materials of these types of resins. After testing a wide variety of resins, it was found that epoxy resins when used with a proper filler seemed most nearly to meet all the target requirements. They cure at room temperature, adhere tightly to portland-cement concrete and other paving materials, have high mechanical strengths, and are extremely insensitive to water and chemicals. The fact that the coefficient of expansion is approximately the same as

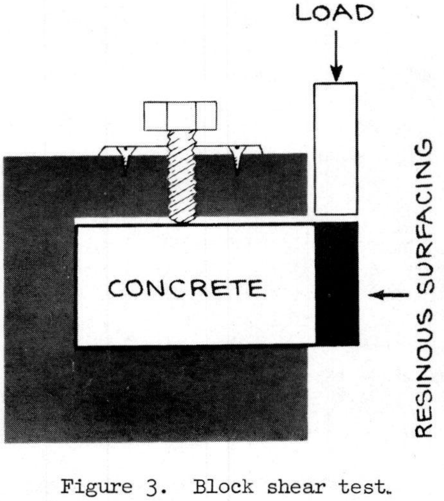

Figure 3. Block shear test.

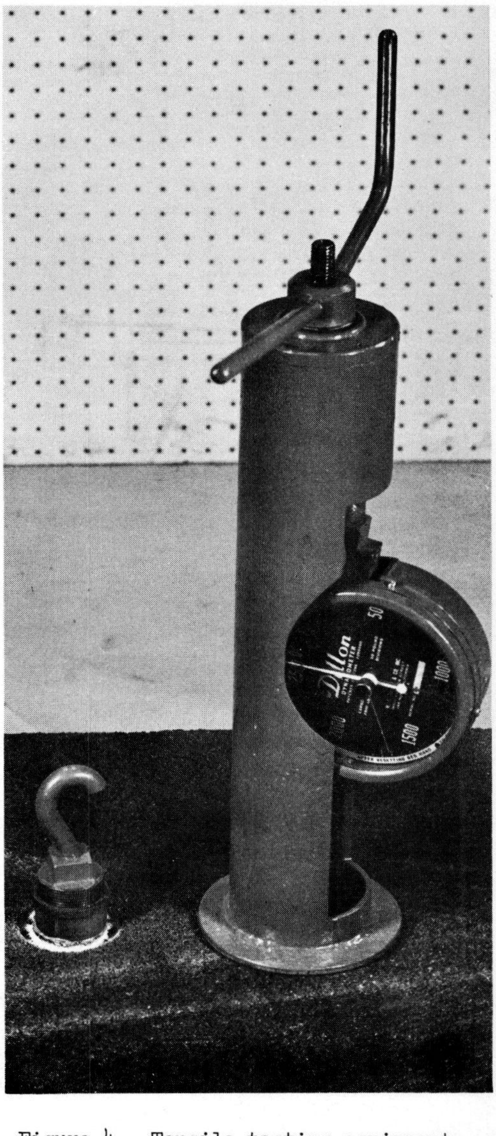

Figure 4. Tensile testing equipment.

TABLE 1

TREATMENT OF HIGHWAY AND BRIDGE SURFACES WITH EPOXY CEMENTS

Initial Test Applications—1954, 1955	Application[1]	Date Applied	Area Sq Ft	Area Intact Dec. 15, percent 1954	1955	1956
Triborough Bridge, New York City	a	8/24/54	241	20	10	5
Pulaski Skyway, Newark, Jersey City, N. J.	a	8/28/54	584	85	75	75(June)
Manhattan Bridge, New York City	a	9/21/54	344	100	100	100
U. S. Route 1, Newark, N. J.	a	8/27/54	373	95	90	90
Housatonic Bridge, Milford, Ct.	a	9/30/54	198	100	100	100
Wilbur-Cross Parkway, Milford, Ct.	a	9/30/54	295	100	100	100
McClay St. Bridge, Harrisburg, Pa.	a	8/29/55	10,000	-	85	80
Wilbur-Cross Parkway, Toll Booth Milford, Ct.	a	9/12/55	12,000	-	90	70
Perryville Bridge, Perryville, Md.	a	9/29/55	1,100	-	50	40
1956 Test Applications						
Wilbur-Cross Parkway Toll Booth Milford, Ct.	a	5/15/56	3,500	-	-	100
Triborough Bridge, New York City	a	5/23/56	240	-	-	100
Triborough Bridge, New York City	b	5/23/56	900	-	-	100
New Jersey Turnpike, Deepwater, N. J.	b	6/10/56	5,760	-	-	100
Plant Accessway, Houston, Texas	b	6/18/56	3,486	-	-	100
Long Run Road, McKeesport, Pa.	b	9/28/56	7,040	-	-	100
179th St. Tunnel, New York City	b	10/8/56	4,000	-	-	100
George Washington Bridge, New York and New Jersey	a	10/22/56	3,600	-	-	100

[1] a, applied over portland-cement concrete and
b, applied over bituminous concrete.

Since 1953 about 40 applications have been made in industrial plants for service in heavy-duty traffic. They totaled approximately 45,000 sq ft and have been essentially 100 percent successful.

portland-cement concrete is very important. Laboratory work continued to the point where it was possible to select the proper type and particle-size distribution of aggregate for the under course, filler, and top surfacing. The physical properties and performance levels of Relcote which were established in this investigation showed a coefficient of friction to rubber (tire) both dry and wet much higher than the friction coefficient of rubber to dry concrete, tensile and compressive strengths many times greater than that of the strongest concrete, and adhesion to all highway paving materials higher than the substrates' adhesion to itself.

The encouraging laboratory results obtained in this study led to the application of test patches of this material on various highly traveled highways and bridges. This was done to determine the effects of weather, traffic wear and, of course, to convince the highway engineer of the merits of the product. A large number of installations were made on roads, in plants, and in warehouses during 1954 and 1955 involving areas from 100 to 12,000 sq ft per application and totaling over 50,000 sq ft. Bridges and highways in various locations were surfaced without difficulty using mostly manual methods. A summary of these earlier applications is included in Table 1.

In applying this type of surface treatment two methods are generally used. In both, the epoxy resin binder is first mixed with the curing agent. Equipment has been developed for continuous mixing and application to a highway, but small quantities can easily be mixed in a few minutes by hand, or relatively large batches in an ordinary concrete or plaster mixer. In the first method, which is only recommended for relatively smooth surfaces such as new portland-cement concrete or bituminous roadways, the catalyzed resin containing no aggregate is applied to the cleaned road surface by means of a squeegee, broom, or a roller similar to that used for applying paint. Immediately afterward, fine sharp aggregate is strewn over the liquid resin.

In the second procedure, fine aggregate can be added to the resin while it is in the cement mixer before application to the highway. Figure 1 illustrates the relative quantities of materials used. The resulting mortar is applied to the surface and spread with a manual or mechanical screed. This method is preferred when thicker layers of the coating are to be applied, especially over portland-cement concrete roads which

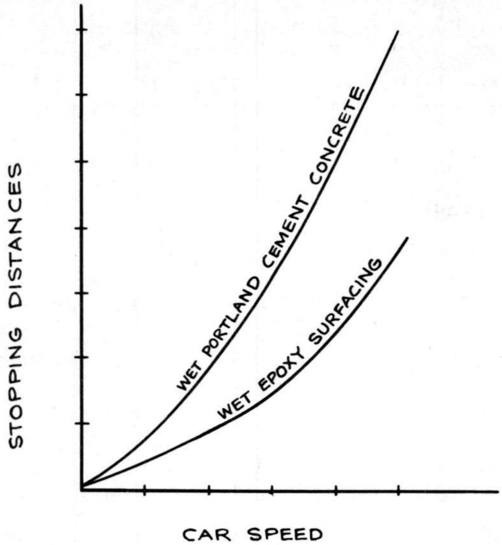

Figure 5. Stopping distances over wet surfaces.

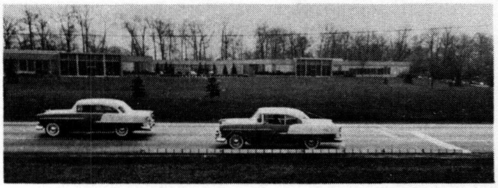

Figure 6. Skidding distances over wet concrete and wet resinous cement surfaces.

exhibit uneven surfaces.

The resin is then allowed to harden at ambient temperatures. In summer weather, the hardening can be accomplished in as little as one hour. In cooler weather, longer periods are required. A sandpaper finish with grit particles that will not pull out of the wearing surface results.

Most of the patches of this surfacing material which were applied in 1954 and 1955 on highways pointed up the excellent resistance to wear and showed great promise as an aid in eliminating skidding accidents. In some cases, however, adhesion failures occurred in these pioneering applications. In a few cases cracks appeared and, subsequently, part of the surfacing material scaled off. These results were contrary to the high adhesive bonding strength obtained in the early laboratory work where it was nearly impossible to break the bond of epoxy cement to concrete without first producing a break in the concrete itself. Furthermore, since most installations were 100 percent successful, and in no case was complete adhesive failure experienced, it was evident that the problem could be solved; it was necessary only to determine the reasons for the successes. Therefore, an intensive program was undertaken to develop laboratory methods which could be correlated with the controlled experimental work carried out on an actual highway carrying typical traffic loads. It was hoped that from such a program the effects of resin composition, cleaning techniques and application methods as well as daily temperature changes, traffic loading fatigue, rainfall, acceleration and deceleration of vehicles could be more clearly determined.

TESTING METHODS

In the early phases of this project, with the exception of visual evidences of wear and cracking or scaling, there were no good means of evaluating this type of surfacing

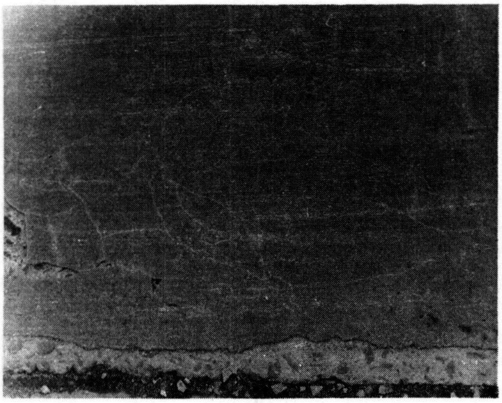

Figure 7. Cracking failure of resinous cement.

Figure 8. Test applications on U. S. Highway.

material. It was desirable to have some type of test that would correlate quickly the effect of variations in formulation changes, surface pre-treatments, or application methods with performance. Since little or no loss in tractive property was experienced in any of the first test applications, although failures in adhesion had occurred, it was felt that bond strength was more important than other properties and that a meaningful adhesive test would be most useful. Because of the unique nature of this surfacing material and its much greater strength as compared to concrete, no acceptable test methods were then available. As a result, three general test procedures illustrated in Figures 2, 3 and 4 were devised and evaluated.

The two that appeared most reproducible and meaningful, and at the same time duplicated at least some of the stresses induced in road surfaces by traffic and temperature changes, were the block shear test and the adhesion test. The former appears most satisfactory for laboratory testing and the latter for actual road testing.

The tensile test has proved of value not only in testing highway coatings but also in actually pre-evaluating the concrete or asphalt surface prior to resurfacing. With this test it can be learned whether a new concrete is completely cured, or in the case of old concrete, the extent to which chemical and mechanical scaling and spalling may have weakened the concrete surface. A high-strength bond to the concrete is worthless, of course, if the concrete surface is so weak that it will later scale off; hence, information of this kind is imperative for this type of surface treatment.

In addition to adhesion tests, experimental laboratory formulations were also evaluated for resistance to the effects of freeze-thaw, weather and salt water in accelerated tests.

Freeze-thaw resistance studies were carried out with concrete blocks the size of a common building brick. The largest face was surfaced with resinous mortar and, after curing, the specimen was subjected to the following conditions, soaking in water for 1½ hours, freezing at -40 F for 1½ hours and heating in an oven at 180 F for 1½ hours. This cycle was repeated to failure. As was the case with adhesive testing, the concrete failed before the resinous cement surface or bond was harmed. As a matter of interest, several other classes of resins which were also tested in this manner lost adhesion during this rather severe test long before the concrete disintegrated. The low shrinkage on curing of the epoxy resin as compared to other resins is believed to contribute to its superior performance.

Weathering tests were carried out in a commercial Weatherometer of the type used to test paints, textiles, and other materials for outdoor durability. The standard cycle of 102 minutes at 140 F in simulated bright sunshine produced by a carbon arc light and 18 minutes of rainfall produced by a small water spray is repeated three times each hour. Resin-treated concrete surfaces exposed to these conditions withstood over 500 hours of testing without ill effects, at which time the tests were terminated.

Resistance to the effects of salt water was determined by immersing a concrete block surfaced with a grit layer in a 10 percent solution of sodium chloride at room temperature. The strength of the resin bond remained greater than the strength of the concrete after 90 days of such exposure.

HIGHWAY STUDY

Through the cooperation of the New Jersey State Highway Department, permission was obtained to use a mile-long section of highway for this experimental program. The roadway was one of the main feeder highways from Pennsylvania to New York City. Some of the concrete was 35 years old, and some less than one year old. Many areas were smooth, but heavy wear, scaling, and cracking existed in others. The program was organized to coat approximately 30,000 sq ft of the highway with modifications of the original epoxy cement system.

The study consisted of three separate phases: (a) the pretreatment of the concrete, especially that which was impregnated with oil drippings, (b) variations in composition of the EPON resin cement and (c) a study of various methods of application and their effect on performance of the surface treatment. Over 90 different variables were studied during this project. Periodic inspections and tensile testing of the patches were made to determine the relative merits of each of the compositions, or the effect of the other factors involved.

In the study of concrete surface preparation, numerous methods for oil removal were studied. They included steam, solvent, detergents, mechanical methods, chemical methods, and resin additives. Each of these methods was tried on from 3 to 30 different patches and epoxy cement applied over the surface. Quantitative evaluation of the relative effectiveness of the cleaning methods was made using the laboratory-developed adhesive tensile tester. Typical results of this test when employing the various cleaning methods are summarized in Table 2.

It must be emphasized that these test values may be significantly affected by the type of surface and that somewhat different results might be obtained on concrete with a history different from that used in this particular study. In addition, since these evaluations are based on results obtained with less than six months of exposure it is entirely possible that additional aging could reverse some of the results obtained; however, this is doubtful since from a consideration of data obtained on some of the older installations it appears that there is little change in adhesive strength of these systems after the first three months.

As stated earlier, the epoxy cement system is essentially a resin-aggregate mortar. Since the mortar is applied in layers ⅛ to ⅜ in. thick, the aggregate used is necessarily confined to a rather small particle size of less than ⅛ in. The aggregates used in this program included silica in the form of bank sand, crushed quartz, or beach sand, aluminum oxide, glass and carborundum. Most of these were used in more than one sieve size. Of course, the main reason for and the main effect of aggregate addition is to provide high traction. Some difference in strength and wearing qualities of the different materials has been observed; however, this is thought to be of a minor nature at the present time, because even in areas which have been exposed three years to heavy traffic, ordinary becah sand has shown little wear, with good retention of skid resistance.

The use of pigment was also studied briefly. Most pigments can be added to the new cement system without any effect on application technique or performance. A white pigmented epoxy cement surface appears to be highly beneficial in tunnels where maximum light reflectivity is desired to minimize the contrasting low light value when entering the tunnel on a bright day. Glass beads of the light-reflecting type can be added to the surface for extra brilliance. A narrow stripe of epoxy cement pigmented either yellow or white and applied on the center of a highway can be used to make an excellent semi-permanent traffic striping paint. Other colors could be added to provide a code indicating to the motorist school zones, curves, stop signs, or complex intersecting routes.

TABLE 2

RUPTURE STRENGTH OF EPOXY CEMENT OVER VARIOUS SURFACE PRETREATMENTS

Control, no cleaning	84 psi
Detergent cleaning	116 psi
Solvent cleaning	152 psi
Mechanical cleaning	152 psi
Steam cleaning	208 psi
Resin modified	309 psi
Chemically cleaned	368 psi

The third phase of the investigation on the highway concerned application methods. Naturally, work on this project was done largely by hand since only small areas were involved. Screeds, brooms, squeegees, rollers and several types of sprayers were evaluated. Within narrow limits, the manner of application has so far shown little effect on performance, wear, or bond strength. The data gained here did provide sufficient information to select suitable machinery and equipment. Because of the uniform surface it produced, economy of operation, and simplicity, the roller-coating method was incorporated into a prototype machine which can lay down resinous cement at a rate of approximately 200 sq ft per minute. The original machine has been used successfully in large scale experimental applications. Manpower requirements can be cut significantly by this mechanized means of application which, of course, will reduce over-all cost.

The present equipment includes a proportionating mixer for resin and catalyst mounted on a truck bed. The mixed resin is flowed by gravity onto the roadway surface from a trough through several adjustable orifices. The resin is then spread evenly by means of large-sized paint rollers attached to the truck and sand applied to the treated surface with a wide seed spreader. Results to date have been sufficiently encouraging that several simplifications are being incorporated into an improved model.

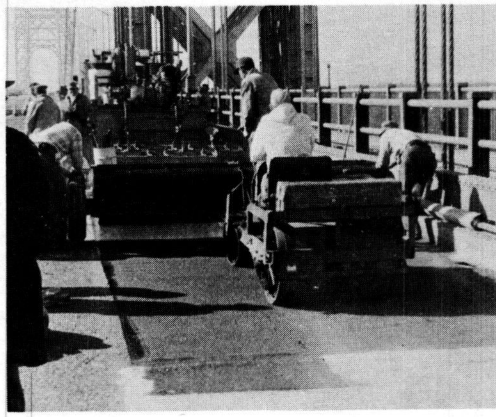

Figure 9. Application of epoxy cement on George Washington Bridge.

During the numerous applications made on Route 22, it was found that the epoxy cement, which is quite fluid as applied, penetrated and filled any small cracks which were present in old concrete surfaces. Upon hardening of the resin, the crack is effectively sealed against the disintegrating effects of water and weather. Another advantage of this liquid application is the leveling off of small holes and depressions which may be present in the concrete so that rough roads resurfaced with a thin layer of epoxy cement become much smoother riding. With the normally-used grit size it has been found that such resurfacing produces highways noticeably quieter. This is especially evident at higher speeds where tire noises are drastically reduced.

Several types of EPON resin were used in this study. All performed equally well, and the resin selected would be the one most suited to the individual job requirements.

Since the curing of these resins is prohibitively slow at winter temperature conditions, methods of artificial heating were also studied on this project. By means of the systems which were developed the working season has been extended into the early spring and late fall months.

Although results already obtained during this highway program have been extremely useful and encouraging, observation and testing will continue to be carried out for the next several years. This testing area located on US 22 in Union, New Jersey, is available for inspection at any time by interested individuals or groups.

LARGE-SCALE EXPERIMENTAL APPLICATIONS IN 1956

Utilizing the knowledge gained in the laboratory program and in some degree the information obtained from the highway work, seven relatively large applications were made during the summer and fall of 1956. These included resurfacing of both portland cement and bituminous concrete roadways. They are listed in Table 1 along with earlier highway installations for easy comparison. A brief comment about some of these tests may be in order here.

The installations made at the Wilbur-Cross Parkway and part of that on the Triborough Bridge (on portland cement) were replacements of failures which had occurred because of inadequate preparation of the roadway surface in earlier tests. After seven months' service no failures have been experienced on either job.

The application on the George Washington Bridge operated by the Port of New York Authority points up one of the secondary advantages of this surfacing material. A second level is to be added to this bridge to accommodate the increased flow of traffic since it was constructed 25 years ago. This, of course, will greatly increase the weight of the structure, and whereas the present deck is showing signs of wear and will eventually need resurfacing, a 3-in. layer of bituminous concrete may not only reduce the allowable dead load stresses of the structure but would necessitate raising all expansion joints as well. Two types of tractive surfaces, ⅛ to ¼ in. thick, were applied in the heaviest traveled lane. Visual observation, skid tests, and tensile adhesive tests will be carried out at periodic intervals to follow the progress of these test areas.

The experimental application in the 179th Street tunnel, which is one of the approaches to the George Washington Bridge, was made to test the applicability of this new resinous cement as a light reflecting surface. Here, as is the case with most tunnels, the light level difference on bright days is so acute that the eye cannot rapidly adjust to the artificial lighting. The condition is aggravated by dark bituminous roadway surfaces. The formulation used was pigmented white to obtain maximum reflectivity. Lightmeter readings show a 20 percent reflection factor after one month's service compared to a 5 percent value on the adjacent bituminous area. Traction is also improved.

The New Jersey Turnpike application was made over a bituminous surface primarily to obtain a highly skid resistant pavement on the approach to a terminal toll booth. The wear on the exposed limestone aggregate in this area of the highway has produced a polished surface. Qualitative evaluation of the resurfacing shows it to provide a high safety factor where severe braking applications are the rule. The surface shows some loss of grit at this time, but without impairment of tractive properties.

Actual measurement of the skid-resistant qualities of some of these surfaces have been made both with a James Decelerometer and by measuring skid tracks on braking at various speeds. On wet pavements both methods show the stopping distance on epoxy-cement surfaces is about half that of worn portland-cement concrete. This is illustrated in Figure 5.

CONCLUSION

As a result of these studies, it can be concluded that Relcote can be applied with good results over nearly all types of highway surfaces provided that a careful analysis is made of each job before application. The following factors must be observed:

1. Employment of proper method of removal of oil and grime deposits.
2. Use of tests to determine that the tensile strength of the surface layers of the concrete is at least 150 psi. Surfaces must be treated until this minimum strength is obtained.
3. Employment of the proper grit and extenders with the epoxy resin.
4. Employment of careful workmanship with trained labor.

When these procedures are followed, it appears that such resinous cement surface treatments for highways should possess the following qualities:

1. Permanent high traction even under wet or oily conditions.
2. Long-wearing properties in hot or cold climates.
3. Excellent resistance to freezing conditions, de-icing salts, solvents and water.
4. No porosity, which protects the original pavement.
5. Light-weight, which is especially useful in resurfacing bridges, where excessive loadings in weight or thickness are undesirable.
6. Easily colored for lighting, safety, or directive requirements.
7. Fast curing to give a minimum interruption of the flow of traffic.

ACKNOWLEDGMENT

The authors wish to thank the many individuals in the following highway departments and agencies, without whose assistance and cooperation this program would not have been possible: Connecticut State Highway Department, Maryland State Roads Commission, New Jersey State Highway Department, New Jersey Turnpike Authority, New York City Department of Public Works, Pennsylvania Department of Highways, The Port of New York Authority, and the New York Triborough Bridge and Tunnel Authority.

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Application of a New Non-Skid Surface Treatment On Connecticut State Highways

WARREN M. CREAMER, Connecticut State Highway Department, and
R. E. BROWN, Shell Chemical Corporation

A newly developed non-skid surface treatment has been applied to the concrete apron and toll booth area at the Milford toll station on the Connecticut Wilbur Cross Parkway. This coating, approximately ¼ in. in thickness, consists essentially of sharp, hard aggregate, approximately 35 mesh, permanently bound to the concrete deck with a thermosetting epoxy resin. Heavy traffic volume through the Milford toll booth, along with the degrading action of de-icing chemicals, had caused an excessive amount of concrete spalling and wear. This resulted in a dangerously slippery area where automobiles must continuously stop and start. The material was applied to this area to prevent skidding, smooth out the rough and spalled areas, and protect the concrete apron from further degradation.

A small crew of men made the application with equipment and materials which are presently commercially available. Although some initial difficulties were encountered, approximately 12,000 sq ft, including toll booths and a downhill approach, were successfully coated in a relatively short time. The good safety record at the Milford toll booth since the application two years ago testifies to the effectiveness of the coating as a skid-proofing material. Frequent physical testing of the coating has indicated little degradation of the coating itself or of its adhesion to the concrete deck since it was applied.

● A NEW PRODUCT for surface treatment of portland cement or bituminous concrete which provides skidproofing of hazardous areas and which appears to have great promise as a protective barrier against weather, de-icing salts, fuels and lubricants, is being tested intensively on Connecticut highways. This material, known as Relcote (Registered Trade Name, Reliance Steel Products Co.) consists essentially of a surfacing course of sharp sand, flint, or other abrasive aggregate utilizing a synthetic epoxy resin binder applied in thin layers ranging down to 1/16 in. over new or old pavements.

In September of 1954 Reliance Steel Products Company of McKeesport, Pa., originators of the new surface treatment in cooperation with Peerless Construction Company of Scarsdale, N.Y. made two trial applications of this material on portland cement concrete surfaces near the Milford Toll Station on the Wilbur Cross Parkway. At the Wheeler Farms Road intersection, 300 sq ft was applied on the westbound inside lane; and 200 sq ft was applied to the eastbound outside lane on the Housatonic River Bridge. These test patches, after 12-months close observation, showed no significant wear or loss in adhesion. Figure 1 shows the leading edge of the test patch applied at the Wheeler Farms intersection after a 2-yr exposure.

On the basis of this performance an experimental contract was given to resurface all critical areas at the Milford Toll Station. The contract called for resurfacing 12,000 sq ft to include all ten toll lanes and 100 linear feet of all the approaches immediately preceding the westbound toll lanes as shown in Figure 2.

This particular area was chosen for large-scale experimentation because of the severe conditions which prevail. The ADT at the Milford Toll Station is 27,000 cars. The traffic load distribution (Fig. 2) shows that lanes 1, 2, 9, and 17 carry very little of this traffic.

In addition to the heavy traffic loads on this highway, abnormally high stresses are applied to the pavement surfaces because of the site location near the middle of a long grade. Thus, the westbound traffic employs excessive braking on the downgrade, and

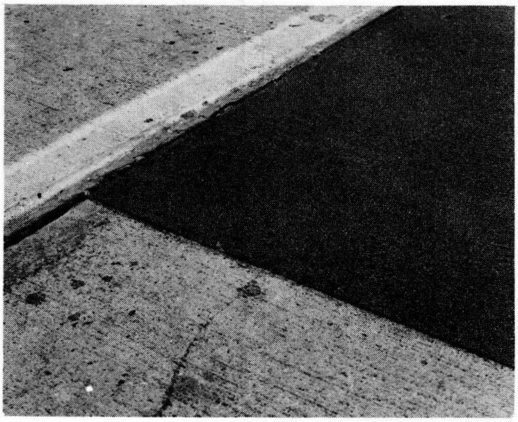

Figure 1. Wheeler farms intersection, close-up of leading edge.

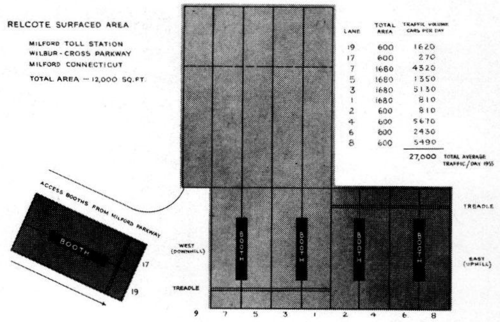

Figure 2. Milford toll station, total area resurfaced.

eastbound traffic, after stopping at the toll booth, applies extra power in acceleration upgrade. The situation of the toll station also necessitates more frequent and generous use of de-icing salts. The severity of this combination of factors is shown in Figure 3 in the excessiver wear, scaling, spalling, and oil deposition which had resulted after only 15 years of service.

In many areas, oil had penetrated the pores of the concrete to a depth of more than ¼ in. The most frequently traveled lanes 3 and 7, westbound, and 4 and 8, eastbound, were in much poorer condition than those less frequently traveled. Moreover, the up-hill lanes, because of traction requirements, were in poorer condition than the down-hill lanes. The heavily traveled up-hill lanes (4 and 8) had tire track ruts more than ½ in. worn into the pavement. The Milford Parkway access booths 17 and 19 are not subject to these abnormally high stresses and contamination because they are located on level ground at the end of a sharp curve which slows the traffic prior to entering the toll booth area.

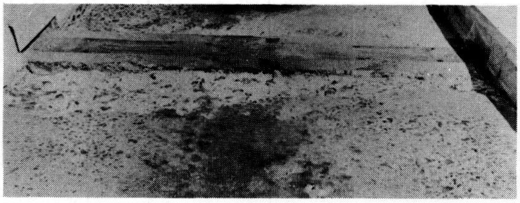

Figure 3. Milford toll station, condition of surface prior to application.

In Spetember 1955, one year after installing the test patches, the resurfacing of the toll station was undertaken. A machine for continuously applying this mate-

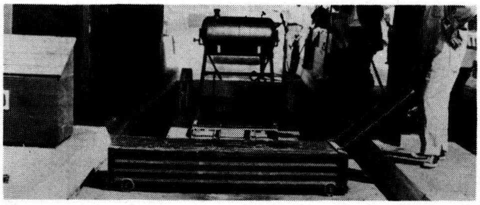

Figure 4. Milford toll station, use of heaters to prepare surfaces prior to initial application.

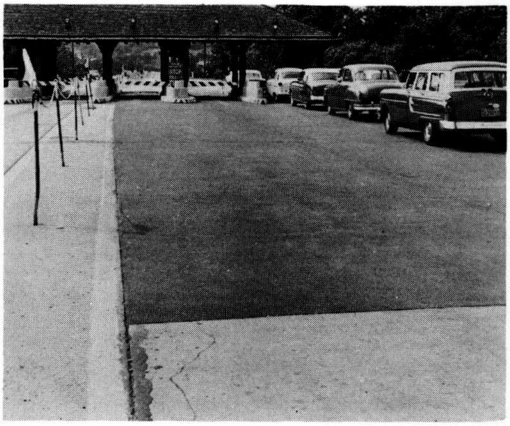

Figure 5. Milford toll station, view of westbound lanes shortly after application.

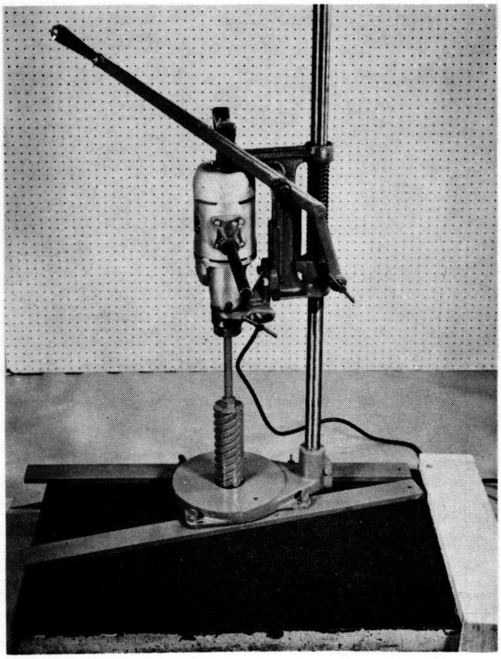

Figure 6. Carbide-tipped core drill in position for drilling.

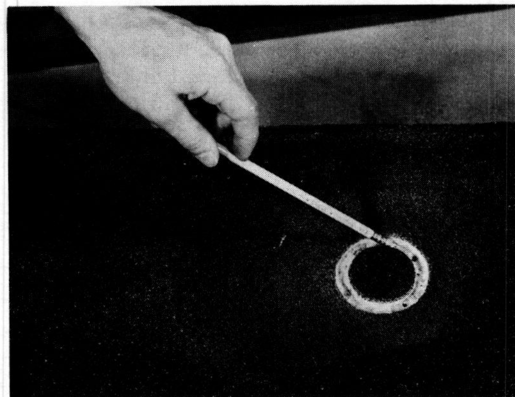

Figure 7. Cored disc after drilling.

rial was in the development stage, and it is understood that a prototype model had been used successfully on recent applications. However, the relatively small area and space restrictions imposed by the toll booth site made the application by manual methods more practical.

Knowing that the success of this surface treatment would be dependent on obtaining a clean, sound bonding surface, a considerable effort was expended in attempting to clean the existing concrete surfaces. Vigorous sweeping was followed by carefully controlled heating with kerosene-fired burners mounted in a sheet iron shield (Fig. 4). It was anticipated that three things would be accomplished by the thermal cleaning: (a) organic contaminants such as oil and grease would be burned off; (b) weakened concrete would be spalled off; and (c) the surface wetting action of the binder would be enhanced. The emphasis was placed on cleaning the booth areas where oil deposition and concrete surface degradation was most severe. In the worst cases, a grease-cutting solvent was applied prior to the thermal treatment.

Figure 8. Machine faced pipe cap bonded to cored disc.

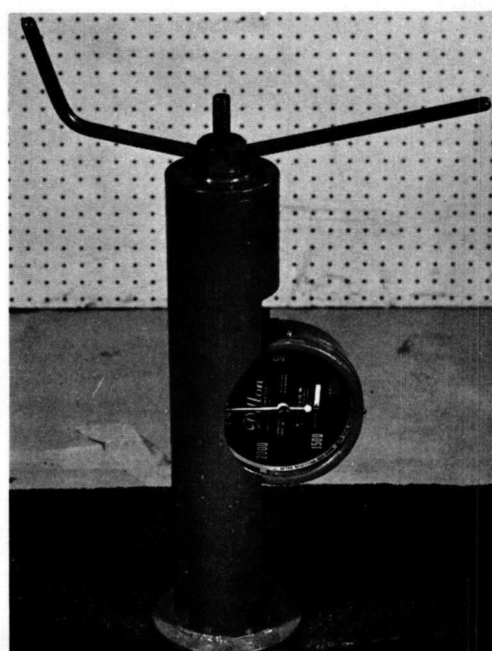

Figure 9. Mechanical testing device for pulling bonded pipe cap in tension.

Immediately following the surface cleaning operation, the resinous binder was prepared for use. This binder, consisting of an EPON (Registered trade name, Shell Chemical Corp.) resin and an organic amine hardener, was mixed in a conventional 3-cu ft concrete mixer. An equal weight of sharp, crushed quartzite sand was added and mixing continued until the sand was completely wetted. This resin and sand pre-mix was then delivered to the surfacing site in concrete buggies where it was manually screeded down-hill with specially designed serrated rubber squeegees to apply 6 to 8 lb of pre-mix per square yard. While the screeded pre-mix was still fluid, No. 30 mesh surfacing grit (fired aluminum oxide) was manually applied in excess at a rate of about 18 lb per sq yd. The surface was then rolled with a lightweight lawn type roller as soon as proper bodying permitted. After the surfacing layer had set to a hard, firm structure, the excess grit was swept up and recovered. The booths were opened to traffic the following morning. The westbound lanes shortly after application are shown in Figure 5.

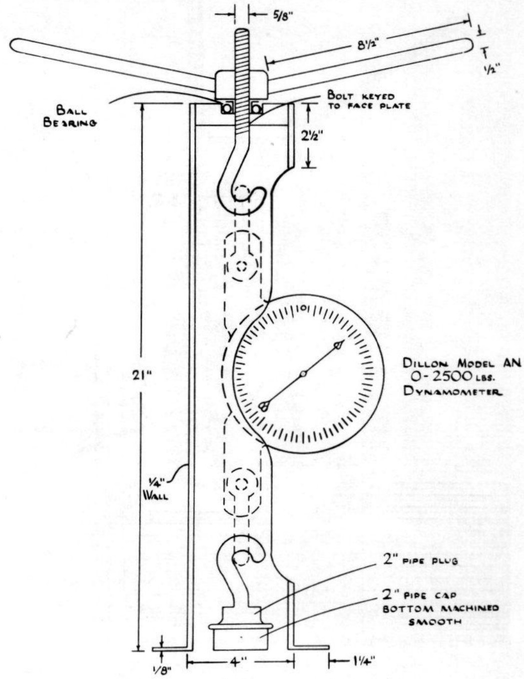

Figure 10. Functional sketch of mechanical testing device.

The ensuing winter and spring months produced some failures in this initial application. An estimated 20 percent of the total area amounting to about 2, 400 sq ft had failed over an 8 month period. The failures were almost entirely adhesive in nature, that is, the surfacing layer had parted from the concrete at the bond line. In all cases, surface contaminants, identified primarily as oil and grease, were noted on the underside of the failed layers indicating that the surface in these areas had not been adequately cleaned despite the diligence with which the cleaning operation had been carried out. The areas of failure were entirely confined to the booths which carried the heaviest traffic loads (3, 5, and 7 westbound and 4, 6, and 8 eastbound).

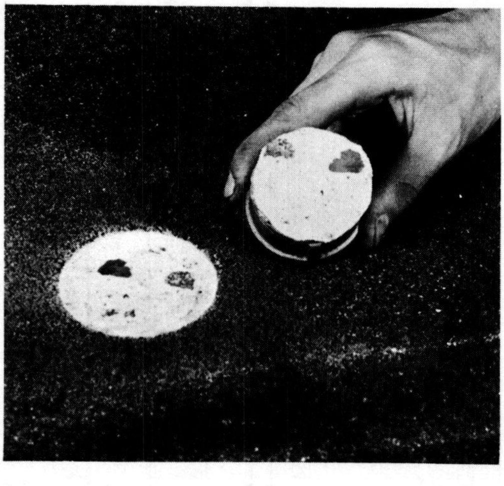

Figure 11. Typical failure in concrete. Dark spot on cap and in concrete indicate split aggregate.

Meanwhile, in the interim months following the initial application, considerable laboratory effort had been expended by the contractor and resin supplier in the development of a test machine designed to evaluate the quality and degree of cleanliness of the concrete surfaces as well as the quality of Relcote to concrete bonds at the roadsite.

This test method consists of drilling a core through the surfacing layer just down to the concrete surface by means of a 2-in. drill fitted with a carbide tipped core bit (Fig. 6). A view of the resulting cored disc is shown in Figure 7. A 2-in. diameter pipe cap, machine faced on the bottom, is then bonded to the resulting cored disc by means of an EPON resin adhesive (Fig. 8). This pipe cap is then heated with a gasoline blow torch to promote rapid hardening of the adhesive in such a way that the Relcote to

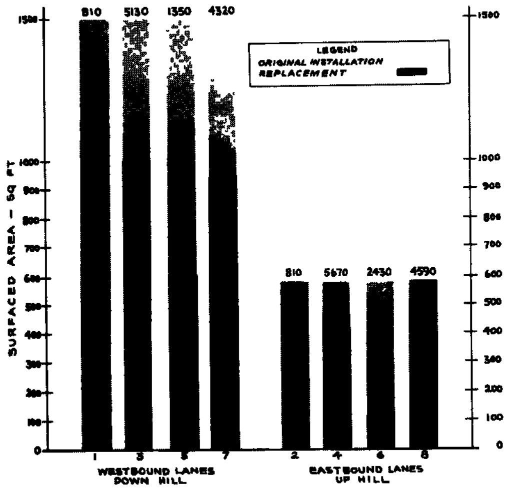

Figure 12. Failure analysis for Milford toll station application.

concrete bond line does not receive any appreciable heat. The bonded cap is pulled in tension by means of the mechanical device (Figs. 9 and 10), until it separates from the surface. The maximum load indicated on the gauge of this device is converted to the unit stress necessary to bring about the separation.

Hundreds of demonstrations, both in the field and in the laboratory, have shown that surfacing layers bonded to clean, sound concrete invariably result in failure of the concrete substrate at values ranging up to 800 psi, clearly showing that the bonding strength of the surfacing layer is greater than the cohesive strength of the concrete substrate itself (Fig. 11). It can be said that, where failure occurs in the concrete substrate, the bond strength of the surfacing layer is no longer being tested but the cohesive strength of the concrete is being tested. This test method can also be applied directly to untreated concrete surfaces and thereby be employed as a simple, rapid means of evaluating the surface strength prior to surface treatment.

Six months after the initial application in March 1956, an extensive study was initiated at the Milford Toll Station with a 3-fold purpose: (a) to throw light on suspicions that the major cause of failure in the initial application was inadequate surface preparation, (b) to ascertain how much of the remaining initial application should be removed and replaced, and (c) to evaluate additional cleaning techniques which had shown promise in the laboratory and to determine which of these methods were best suited to the existing conditions at the Milford site.

The results of the first series of tests evaluating the original application gave strong indication that the major cause of failure was one of surface cleaning. Eighty-two percent of all the tensile tests on the original application resulted in adhesive bond failures at relatively low values, that is, the surfacing layer had parted from the concrete at the bond line.

In all instances of adhesive failure, evidence of oil or dirt was noted on the underside of the surfacing layer. Of the remaining 18 percent which did not fail in adhesion, 12 percent had failed at extremely low values indicating the presence of weak concrete. While the data indicated the immediate cause of failure to be one of surface preparation, a secondary cause of failure can also be noted. Figure 12 indicates the amount of failure in each lane as well as the traffic load distribution. It can be seen that the amount of failure is directly related to the traffic load distribution, that is, high loads produced a high percentage failure, moderate loads a moderate percentage failure and low loads no failure at all. As previously stated, lanes 17 and 19 which carry low and moderate traffic loads, respectively, are not subject to the severe conditions prevailing in toll booths located on the grade, and lane 9 is used only infrequently; consequently no failures have occurred in these lanes.

Although the tensile values were generally low for the entire area, 80 percent of the initial application was still intact. Since data on the bond strength had been obtained in these areas, it was decided to leave them intact in an effort to determine what the minimum bond strength requirements might be.

In addition to evaluating the bond strength of the original application, a second series of tests were run simultaneously to determine the optimum method of cleaning. Additional tensile test data obtained in the failed areas indicated that, of the many methods which had shown promise in the laboratory, cleaning the concrete surface chemically consistently resulted in cohesive concrete failures at relatively high values. This lent additional strength to the contention that the major cause of failure was one of inadequate cleaning.

In May 1956, the remaining areas of failure were resurfaced. The same procedure outlined for the original application was employed except that the surfaces were cleaned chemically instead of thermally. Prior to the resurfacing, the loose material adjacent to areas of failure was removed. In this manner, an additional 10 percent was removed bringing the total area of failure to 30 percent. The remaining 70 percent of the original application has been in place for 16 months with little evidence of further failure.

In June, one month after replacing the failed areas, a third series of tensile tests were run to evaluate the effectiveness of the chemical cleaning. Figure 13 plots the average tensile bond strength of the surfacing layer in pounds per square inch against the number of the lane in which the tests were performed. The graph serves as a comparison between the average bond strength of the initial surfacing on the left-hand side where only superficial thermal cleaning was employed, and the ultimate resurfacing application on the right-hand side where adequate chemical cleaning was employed. Here again is testimony to the importance of obtaining clean surfaces prior to application.

The grey bars indicate that the tests made in these areas resulted in essentially adhesive failures, that is, a parting of the surfacing layer from the concrete at the bond line. The black bars indicate that the tests made in these areas resulted in essentially cohesive concrete failures, that is, failure occurred in the concrete rather than at the bond line. The bar representing lane 5 which is both grey and black indicates that some tests resulted in adhesive failure and others in cohesive concrete failure. The average value of the adhesive failures was 84 psi as indicated by the grey portion of the bar. The cohesive concrete failures obtained in lane 5, where unexplainably better bonding was obtained, in the initial application, tended to raise the over-all average value for that lane.

On December 3 and 4, over one year after the initial application and six months after the ultimate resurfacing, a fourth series of tensile tests were run to check the

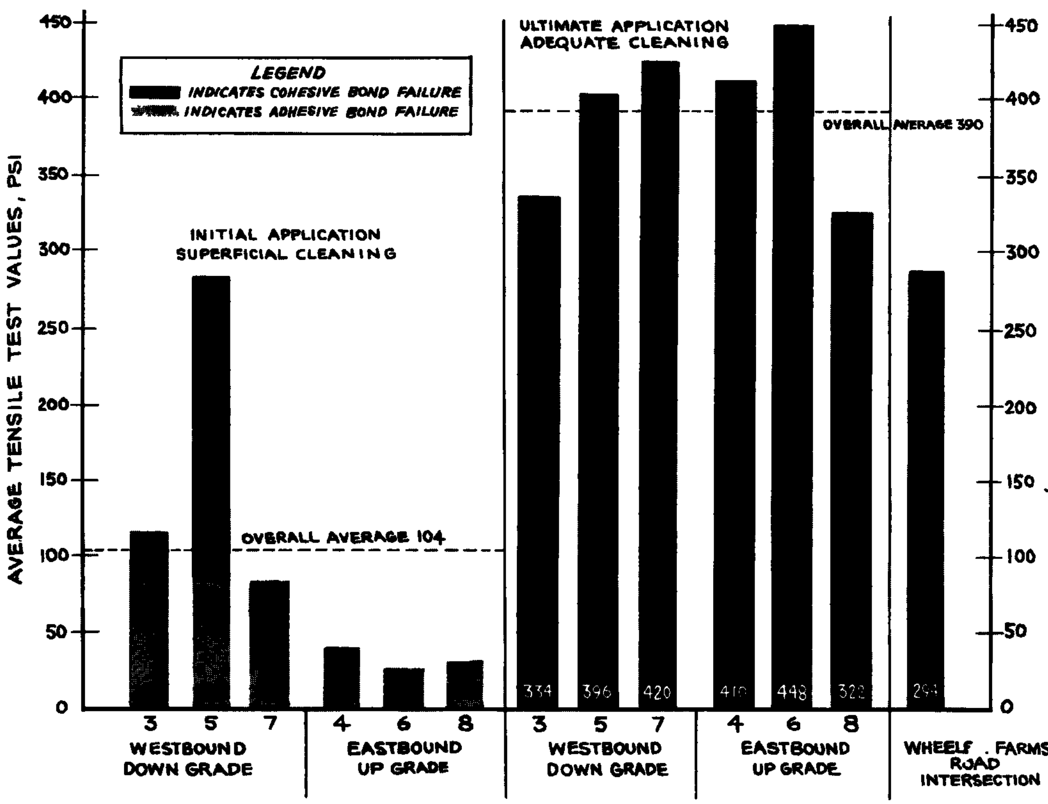

Figure 13. Tensile test results, Milford toll station, comparison of initial and ultimate applications.

effects of fatigue and aging on the bond line. The values obtained were in excellent agreement with those shown in Figure 13 indicating that optimum bonding is obtained very shortly after application and that no detectable loss in adhesion has resulted to date.

On the left-hand side of the graph which summarizes the tensile test results obtained from the original application, the tensile values on the up-hill eastbound lanes show much lower values than those on the down-hill westbound lanes. This is presumably due to the fact that the surfaces of the up-hill lanes were in poorer condition than the down-hill lanes prior to initial application.

The right-hand side of the graph, which summarizes the data obtained from the ultimate application where adequate surface cleaning was provided chemically, shows that the first correlation pointed out for the initial application no longer holds. The values are all high with no easily discernible pattern. It is presumed that this is because the chemical cleaning tends to eliminate surface inequalities by removing weak surface concrete.

Another major and obvious difference is that the average tensile tests on applications over chemically cleaned concrete resulted in failure of the concrete substrate as opposed to failures at the bond line for applications over thermally cleaned concrete. Comparing the over-all average bond strength obtained after chemical cleaning to that obtained after thermal cleaning, nearly a 4-fold increase is noted, 104 to 390 psi.

Finally, on the extreme right-hand side of the graph, the average tensile value for the test patch which was laid down at Wheeler Farms Road is 294 psi with essentially all cohesive concrete failures. These tests were made nearly two years after installation. Additional tensile test data obtained six months later showed no detectable loss in bonding strength. The test patch, at present, is weathering its third winter without significant wear or loss in adhesion. It is not known what the initial tensile test values would have been at Weeler Farms Road. True bonding strength of the coating is also unknown because in all tests the concrete failed before failure occurred at the bond line. Therefore, no direct comparisons with the recently surfaced areas can be made. At the Milford Toll Station the average bond strength of the surfacing layer applied over the chemically cleaned surfaces is significantly higher than that obtained at Wheeler Farms Road, with both having failed in the concrete. Evidence that the fatigue on the bond line has been negligible to date and that 70 percent of the original application having significantly lower bond strengths has not yet failed is especially encouraging. Like the surfacing layer at Wheeler Farms Road, the surfacing layer at the toll station shows no appreciable signs of wear.

A study of accident rates at Milford appears to confirm the belief that this material is performing its function as a non-skid surface. During the 5-yr period prior to the application of Relcote, there were 156 accidents in or around the toll booths. Of these, 20 were accidents due to skidding on wet or icy pavements. This is an average of four skidding accidents per year. Since the Relcote application almost 1½ years ago, there have been no accidents due to skidding in areas where the surfacing layer had been applied. On the average, up to six skidding accidents could have been expected during this period.

In conclusion, experience under extremely severe conditions shows the great promise of this material in protecting pavement surfaces from environmental deterioration and in providing a non-skid wearing course to enhance the safety and driving comfort of motorists everywhere. However, the experiments at the Milford Toll Station are still in progress. Bond strengths will be determined periodically in an effort to learn a great deal more concerning the minimum bond strength requirements and the effects of fatigue, surface cleanliness and traffic loads on service life. Careful evaluation of each individual project must be made before attempting to use this product. Since there is no other satisfactory method of gauging the surface strength of concrete or the degree of cleaning which may be required, it is recommended that, in every case, a preliminary installation be made and subsequently evaluated with the tensile test methods described.

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