Pre-Evaluation of Pavement Materials for Skid Resistance—A Review of U. S. Techniques

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This paper is essentially a review of existing methods, used in the laboratory, for studying pavement materials as related to their skid-resistant qualities. It consists of descriptions of test equipment and testing techniques along with examples of data.

It reports that the laboratory tests have generally developed around two evaluation methods. One is to study compacted pavement mixtures; the other is to test aggregate particles or stone chunks. Both types of methods seem to be useful in evaluating pavement materials prior to their use.

None of the methods reported, however, have widespread use, nor are they entirely alike. Probably the Portland Cement Association and the Tennessee Highway Research Program equipment have the greatest similarity, but test procedures are different.

There are several new methods that are being constructed that include design ideas from older methods. Along with the mechanized laboratory test methods, information on supplemental pre-evaluation tools is reported, including procedures for studying the influence on skid resistance of sand-size siliceous particles, mineral content of aggregates, and pavement permeability.

It is concluded that the pre-evaluation of materials is a practical approach to obtaining better skid-resistant pavements, but additional work is needed to relate laboratory results to field performance.

•THE ability to pre-evaluate skid resistance of aggregates and their combinations prior to inclusion in a roadway surface is desirable. Pavement surface materials should be pre-evaluated for the safety of the driving public, as well as for economic reasons. If unsatisfactory materials can be eliminated, savings in accident costs, maintenance and reconstruction will result.

Presently available laboratory methods of pretesting pavement materials have generally developed around two techniques. One considers the complete mixture; the other considers mixture components. In addition to the laboratory measurement of pretesting pavement mixtures, other supplementary techniques have been used to provide a better understanding of the influence of aggregate particles and mixtures on slipperiness. These techniques include the determination of insoluable residue of aggregate particles, influence of surface weathering, and air and water permeability of pavement mixtures.

A review of the literature in this country reveals that there are several agencies that have made significant contributions to laboratory evaluation of pavement materials. They include Purdue University, Kentucky Department of Highways, the National Crushed Stone Association (NCSA), the Portland Cement Association (PCA), Pennsylvania State University and the Tennessee Highway Research Program. Several agencies including the states of California, Georgia, Maryland, Pennsylvania, and Virginia are extending or beginning preliminary work in establishing laboratory programs.

The presently known methods may be grouped on the basis of relative sample size. For example, the Georgia, Purdue and Kentucky apparatus use samples between 4- and 6-in. diameter, whereas the PCA and Tennessee apparatus use samples of sufficient size for testing with a standard size automobile tire. The NCSA, Maryland and Penn State methods utilize a circular track. In general, however, all methods require a conditioning of the surface, either before or during testing. This conditioning, sometimes referred to as polishing wear, is brought about by a rubber annulus in the case of Georgia, Purdue and Kentucky equipment and automobile tires in the case of the PCA, Maryland, Penn State and Tennessee equipment; a somewhat smaller tire is used by the NCSA. These laboratory techniques are sometimes referred to as "wear machines."

The following factors are reported by these agencies as relating to the materials problem:

For Aggregates	For Mixtures
Angularity	Surface texture
Gradation (size)	Horizontal drainage
Texture (micro and macro)	Vertical permeability
Mineral content	
Porosity	
Susceptibility to polishing	

PURDUE UNIVERSITY METHOD

The Purdue University method as described by Shupe and Goetz (1) and Stephens and Goetz (2) is adaptable to specimens molded in the laboratory or to ones removed from the highway surface. Specimen size is about 6-in. diameter.

The apparatus consists of a vertically mounted mandrel with a head sufficiently large to hold a 6-in. specimen (Fig. 1). A rubber test shoe is mounted on a ball-bearing shaft that is in line with the mandrel containing the specimen. This shaft is restrained from turning by a cantilever bar on which are located SR-4 strain gages. The restraint to rotation is recorded as the frictional resistance. In the test, the specimen is rotated at approximately 30 mph by an electrical motor and the rubber test shoe is forced against the specimen surface through a mechanical arrangement for applying a constant normal force of 28 psi. The applied force corresponds to the normal pressure one would expect to exist between passenger car tires and the highway pavement. The test shoe is held against the spinning specimen for 2 sec and then removed. After a pause of approximately 2 sec the test is repeated and the resistance is reported as a relative value. Water is supplied to the specimen surface during test.

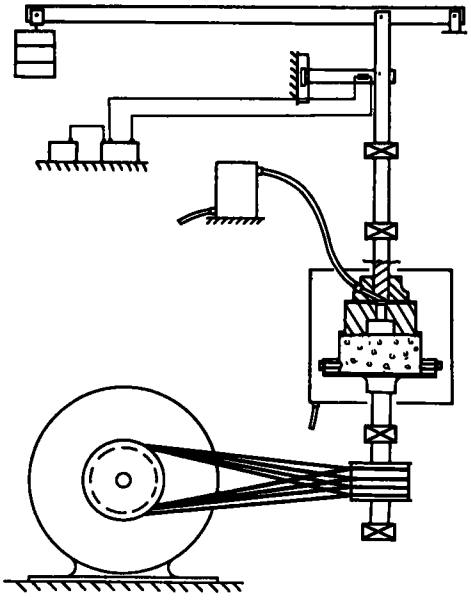

Figure 1. Purdue laboratory machine.

An attempt was made to correlate the laboratory results with field tests by using the stopping-distance automobile. In this correlation effort, the authors concluded that surfaces of medium texture had good

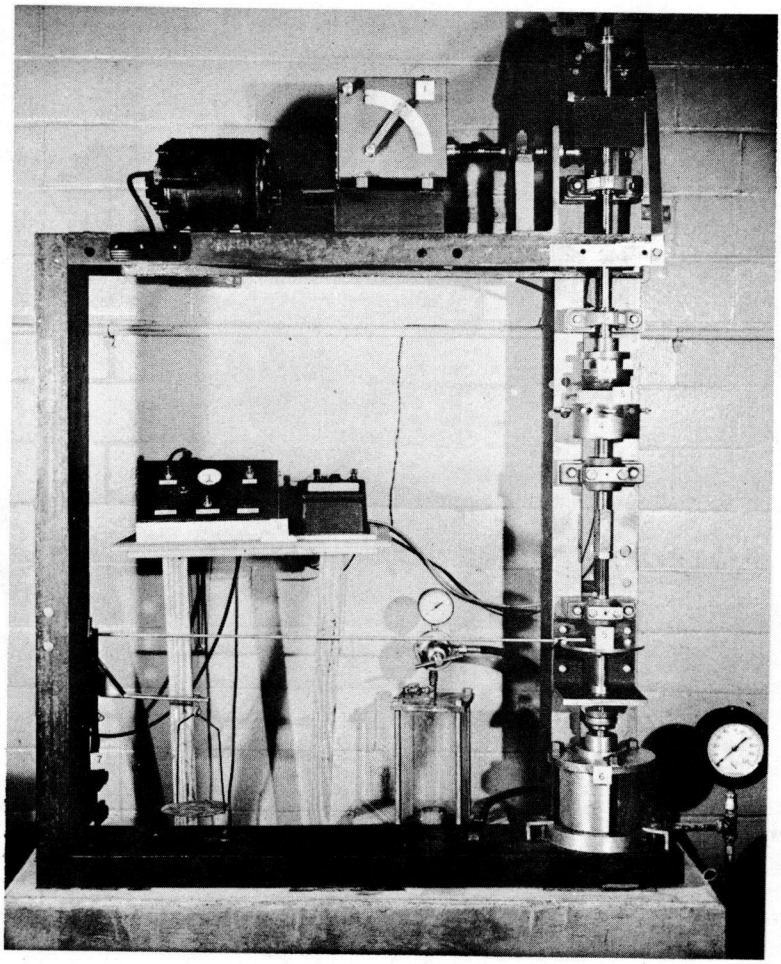

Figure 2. Kentucky friction measuring machine.

agreement between laboratory and field tests. In the open surfaces, the laboratory method indicated poorer anti-skid characteristics than did the stopping-distance method. For an extremely dense surface, the laboratory method showed higher values than obtained by the field measurements.

Typical results with this equipment demonstrate the capability of the method to discern the effect of replacing the fine aggregate fraction with the coarse material in asphalt or concrete mixtures. Results reported by Stephens and Goetz (2) also show the utility of the equipment for studying the relative resistance value of rock cores, aggregate blending, and the effect of aggregate texture. Supplementary research reported by Shupe and Lounsbury (3) relates to the use of the equipment for evaluating polishing characteristics of mineral aggregates. The aggregates were ranked relative to their skidding resistance by the test method.

KENTUCKY DEPARTMENT OF HIGHWAYS

The laboratory research reported by Stutzenberger and Havens (4) considered the testing of stone specimens that were controlled polished. It consists of measuring the resistance to turning of a rubber annulus when placed in contact with a polished stone surface. The device is shown in Figure 2. In operation, an electric motor furnishes the driving power, through a hydraulic torque converter, such that the rubber annulus

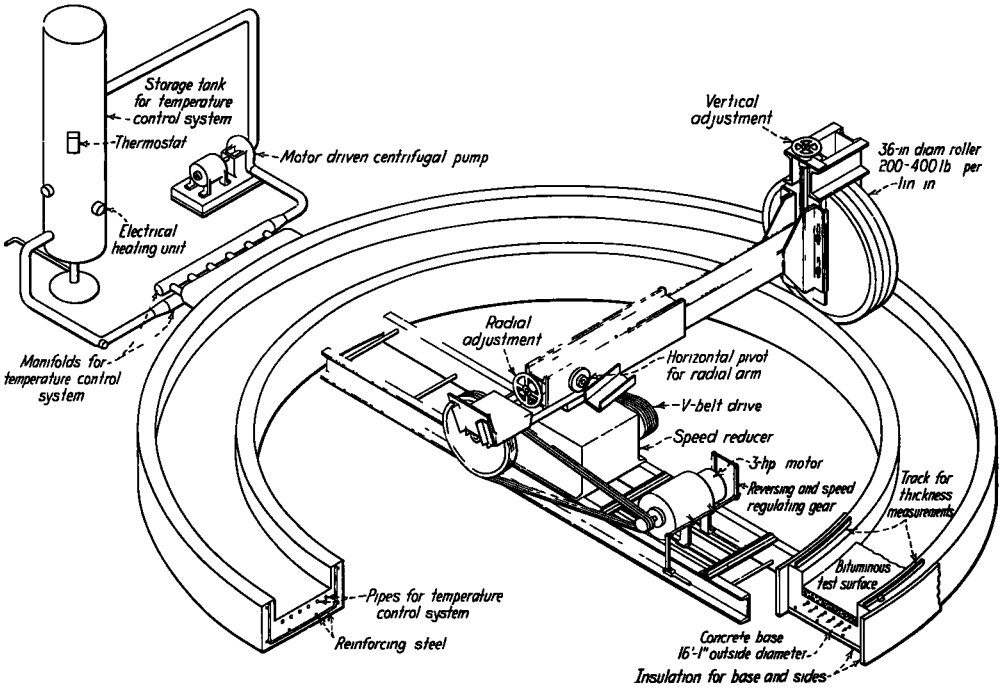

Figure 3. NCSA circular track.

may be rotated at speeds up to 300 rpm when in contact with the stone surface. The specimen supporting device is designed for use with specimens varying in length from 1 to 5 in. and a diameter of approximately 4 in. The loading mechanism consists of a pneumatic cylinder that can provide a normal load on the specimen from 0 to 32 psi. A strain gage bar is attached to the unit that holds the specimen so that when the shaft rotates, the resistance to rotation is transferred to the strain gage bar and is automatically recorded.

The original work using this equipment involved the testing of specimens cored from large chunks of stone obtained from different quarries. These cored specimens were polished by grinding their sawed faces on a wheel that had been faced with an aluminum oxide paper. After initial grinding, the specimens were then ground on a glass plate in a slurry of coarse carborundum and then with the fine grit carborundum. The polishing was continued until the surface was uniform and smooth, after which further grinding was done on another glass plate with a different slurry. The final polishing was accomplished by a buffing wheel. This final stage polishing was continued until three consecutive readings on a reflectometer remained unchanged. After polishing, the stone specimens are tested in either the wet or dry condition. The authors report a method for calculating the coefficient of friction from the test procedure.

GEORGIA HIGHWAY DEPARTMENT

The apparatus being used by Georgia (5) is similar to the Purdue machine, but uses a 10-in. diameter specimen. The purpose for the larger specimen is to permit the use of a British portable tester for the measurement of wear. Also, the Georgia method utilizes a water-abrasive mixture to accelerate the wear process. The apparatus has been in experimental use since 1967.

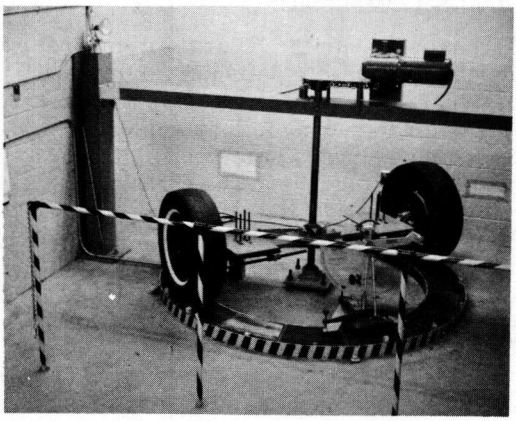

Figure 4. Maryland circular track.

NATIONAL CRUSHED STONE ASSOCIATION

Gray and Goldbeck reported (6) on the NCSA method of pre-evaluation of pavement mixtures. This method also involves polishing the specimen before testing for frictional resistance. A circular track is used for containing the pavement surfaces while they are being polished. The surfaces may be fabricated in the laboratory or obtained directly from the field.

The track is 14 feet in diameter and will accommodate up to 20 different test sections (Fig. 3). The surface preparation consists of rotating a pneumatic-tired wheel many times around the tract, first with water and fine sand on the surface and finally with the surface clean and dry so that only the rubber tire exerts the polishing action. It is believed by the researchers that the circular track technique produces surfaces that closely resemble those formed by normal vehicular traffic.

After the specimens have been polished, measurements of slipperiness are made with the NCSA bicycle wheel. This wheel is supported in a frame and is placed directly on the pavement section to be tested. The tire is ground off exposing the tire fabric over half of its circumference; the other half of the tire retains its full thickness of tread. Slipperiness is measured by rotating the tire to bring counterbalance weights attached to the rim to the uppermost position and the height of the wheel is adjusted so that the wheel turns freely except when the thick portion of the tire is down on the surface.

The wheel is released allowing the weights to rotate it so that the thick portion of the tire strikes the pavement surface, thereby raising the wheel slightly in the slotted supports which hold the axle. The wheel is then supported only by the surface, and it continues to turn until brought to rest by the friction between the tire and the road. The more slippery the pavement the greater is the angle of turn required to bring the wheel to rest. An average of eight readings is taken in order to indicate the pavement slipperiness.

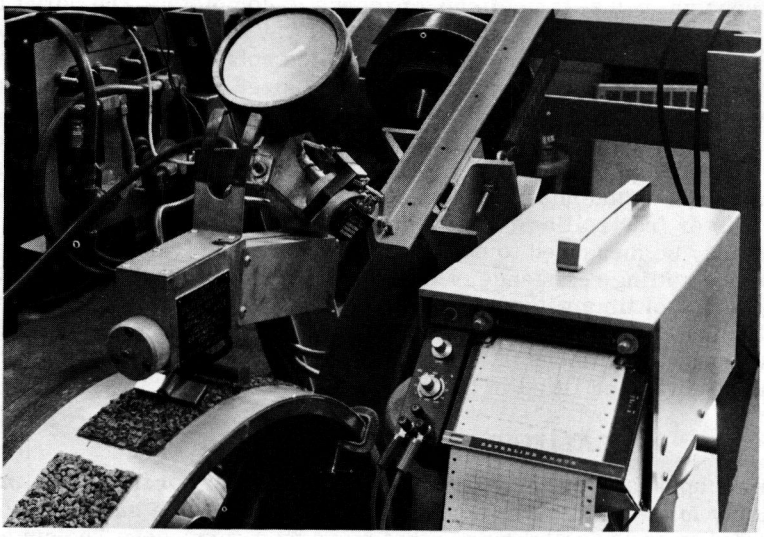

Figure 5. Penn State rotary wear machine.

MARYLAND STATE ROADS COMMISSION

The Maryland State Roads Commission (7) is moving into the laboratory for pre-evaluating pavement mixtures, and has developed an aggregate polishing device that has the features of a circular track (Fig. 4). Concrete as well as bituminous mixes may be tested. Test specimens are trapezoidal with approximate inside dimensions of 8 in. by 14 in. and 11 in. long. After the specimen surfaces have been polished, a British portable tester is used to evaluate their skid resistance. The circular track polishing device consists essentially of two wheels mounted 6 ft apart on a common axle. The wheels are rotated by a 3-hp gearhead motor at approximately 22½ rpm. The wheels can be adjusted to toe in, toe out, or rotate in a plane perpendicular to axle as well as track each other or run at slightly different radii. Provisions have been made to add surcharge weights to the wheels to attain a range of desired loads. The test tires are automobile size and have a slick tread.

In normal operation, four replicas of the same mix are tested. Two specimens are adjacent to each other and the other two are placed on the opposite side of the track. Generally the wearing process is stopped at selected intervals and each specimen tested with the British portable tester. Although only preliminary work has been done, the researchers have noted that with a typically poor aggregate the BPN number is 58 after about 1000 revolutions and this decreases to a BPN of about 49 after 40,000 revolutions.

The research is continuing with the initial intent of standardizing the process and establishing standard mixes against which others will be judged.

PENNSYLVANIA STATE UNIVERSITY

The Pennsylvania State University (8) also has three polishing devices, one of which is a circular track. One device has been referred to as a "reciprocating pavement polisher" which is used to polish individual aggregate particles that are mounted on a 12-in. square metal plate. Results with this device led the researcher to develop equipment to polish aggregates with a rotating tire. This device is referred to as a rotary wear machine (Fig. 5) and is believed to be more representative of the polishing process that occurs under traffic on the roadway. The machine operates by running an automotive tire against pavement samples that are mounted on the outside of a rotating drum. The test tire wheel is run against the drum at the chosen speed, load, and inflation pressure. Polishing agents are frequently introduced to accelerate the polishing wear. During test, the coefficient of friction is measured at intervals and its decrease is used as a measure of the progress of test. When the coefficient approaches a constant value, the polishing process is complete. The "drag tester" utilizing a BPN-type test shoe is mounted in such a way to permit measurement of the coefficient as the drum containing the test samples rotates. Test samples are 1 by 14 in. and consist of selected aggregates that are sized and glued to aluminum panels for attachment to the drum. The drum speed can be controlled between 30 and 50 mph. The other test parameters such as tire inflation pressure may be varied to suit test conditions. In addition to these two polishing devices, Penn State has a circular track (Fig. 6) which uses an automobile wheel. It can be operated under load at different amounts of slip or free rolling. Speeds are controlled from 5 to 24 mph. The torque on the wheel may be measured to obtain the friction force transmitted from tire to pavement or the rolling resistance of the wheel. It is designed to run continuously over a long period of time without attendance. The apparatus is used for wear test on tires or polishing of pavement surfaces and can be operated under controlled environmental conditions. Specimens of pavements may be made directly in the machine or cut from the roadway and fitted in the machine.

CALIFORNIA DIVISION OF HIGHWAYS

California's apparatus (9) may be used in the laboratory or field. It is presently used almost entirely in the field. The device (Fig. 7) consists of a small trailer-type tire that is mounted on two parallel guides that move on a carriage. The guides are rigidly

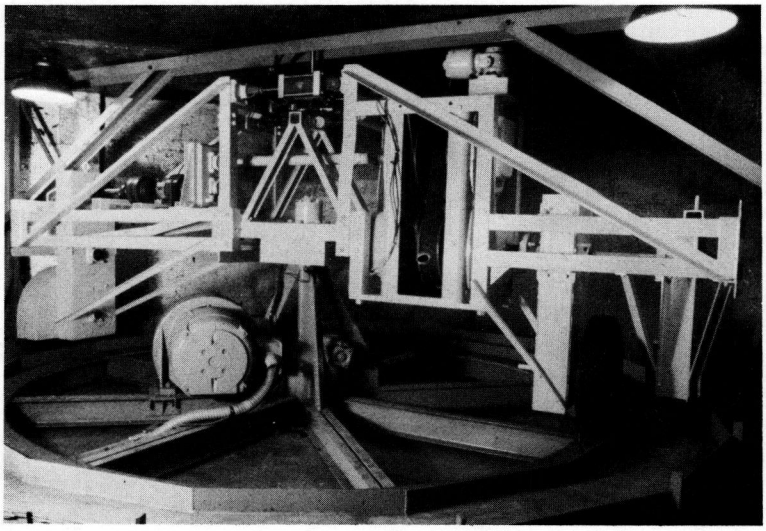

Figure 6. Penn State circular track.

connected into the frame of the assembly and are firmly fastened to a restraining anchor. In conducting the test the tire is brought to the desired test speed and is then dropped instantaneously to the test surface. Usually the test speed is 50 mph. In the pretest condition the tire is raised and adjusted to about ¼ in. above the test surface. The coefficient of friction is determined by reading the calibrated gage attached to the guide rods.

Although this method has been used to rate pavement surfaces in the laboratory, it is now almost entirely used in the field for locating and monitoring potential slick areas. In field operation it is attached to a bumper hitch of an automobile for proper positioning on the pavement.

TENNESSEE HIGHWAY RESEARCH PROGRAM

Whitehurst and Goodwin (10) reported on a device for determining the relative potential slipperiness of pavement mixtures prior to their use. It consists of an automobile wheel driven by an electric motor at a desired constant speed. With the test wheel spinning against a specimen surface, the power required to drive the wheel is considered to be a measure of the specimen surface resistance. As the surface becomes more slippery, less power is needed. Figure 8 is a general view of the test apparatus. It is used for testing specimens 6 by 8 in. up to 36 by 36 in. and 6 in. thick. Usually the specimens are about 24 by 24 in. and six tests are conducted on each specimen surface. Specimens may be fabricated in the laboratory or acquired directly from cut sections of the roadway. In addition to bituminous concrete, portland cement concrete, blocks of stone, and thin surface treatments may also be evaluated.

When in operation, the drive motor maintains a constant wheel speed of 10 mph under a normal pressure of 270 lb. The equipment is designed to operate unattended for conducting tests continuously for a long period. As a rule, however, four 1-hr tests constitute a "run" on each specimen surface. Generally speaking, no effort is made to provide accelerated wear of the pavement surface, although this can be done if so desired.

Test results are graphically presented with the ordinate of the graph representing power consumption of the motor with the wheel spinning against the specimen surface; the abscissa for the data graph is as test time. The chart paper of the recording wattmeter can serve directly as the graphical display.

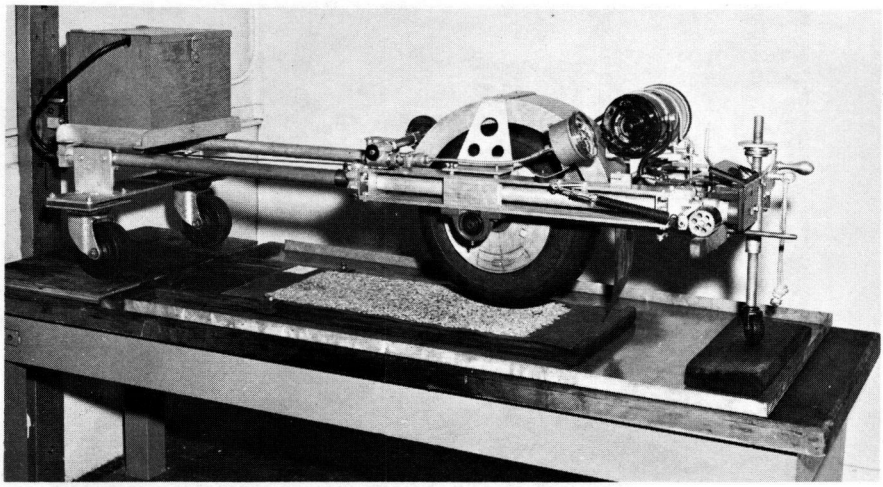

Figure 7. California slipperiness measuring device.

PORTLAND CEMENT ASSOCIATION

The laboratory studies of the Portland Cement Association are reported by Balmer and Colley (11). Their initial work was directed to the objective of determining the influence of aggregate properties on the skid resistance of concrete pavements. The test machine, patterned after the Tennessee machine, is shown in Figure 9. Essentially, it consists of a 25-hp electric motor mounted above an automobile differential assembly. The differential has been modified to provide a direct drive with the motor connected to the drive shaft through a series of belts and pulleys. The motor provides the power to rotate the wheel and tire against the test specimens. The tire is rotated at a constant speed of 20 mph and loaded with a normal force of 600 lb. The normal force is produced by deadweights mounted on a lever that acts against the supports for the test specimens. Water is conducted to the top of the test tire to aid cooling when the test is run continously. The ASTM Standard Tire for Pavement Tests (E249-64T) is usually used. During tests, an electric vibrator stimulates the flow of fine sand that

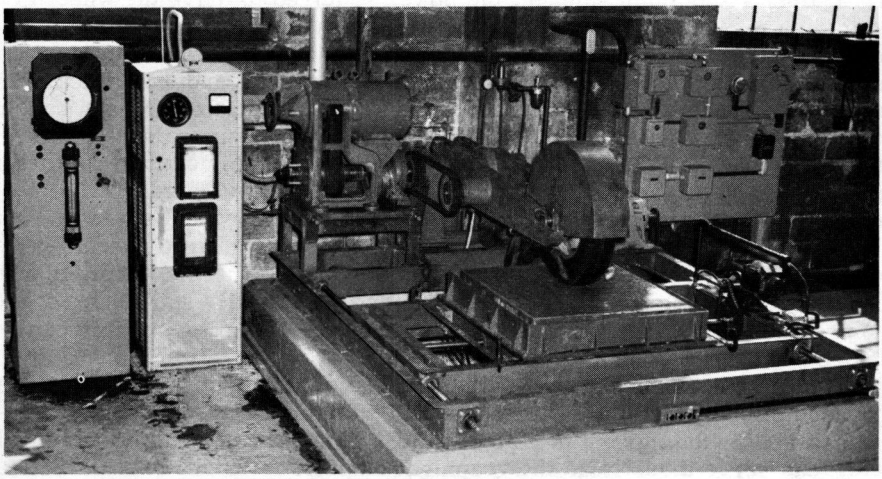

Figure 8. Tennessee slipperiness measuring machine.

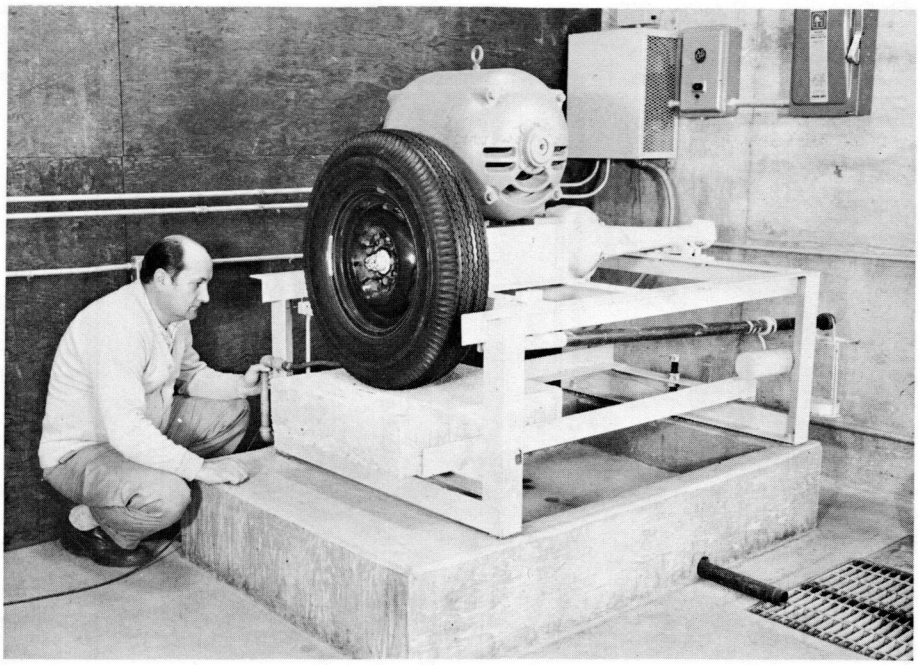

Figure 9. PCA slipperiness measuring machine.

is blown into the water stream to accelerate specimen wear. Test specimens in the order of 24 by 24 by 6 in. may be accommodated in the machine. They may be tested under either wet or dry conditions, but generally they are tested wet.

The testing procedure consists of placing the pavement specimen in the machine, turning the water on to keep the specimen surface continously wet, and energizing the electric drive motor to bring the test wheel to a speed of approximately 20 mph. After the machine is operated without load and the recording wattmeter is adjusted to zero, the specimen is lifted against the rotating tire and the normal test load of 600 lb is applied. During the first phase of the test, the tire rotates continously on the specimen for 75 min. In the second phase, a fine Ottawa sand is fed from the vibrator and blown onto the specimen so that it passes under the rotating tire that is in contact with the specimen. After two hours of sand abrasion, the third phase of the test is continued without sand for an additional 75 min. It is during this phase that the frictional resistance of the worn pavement is assessed.

Data from the test are in the form of a graph that relates a "wear index" with the time period of test. The wear index is considered to be a comparative measure of the skid resistance of the material, and is taken as the electrical power, in kilowatts, that is required to rotate the tire against the pavement specimen. Results are reported at the end of 270 min of testing. Such factors as concrete finish, exposed coarse aggregate, aggregate size, use of abrasives on concrete to develop frictional resistance, and the effect of different surface treatments in the restoration of skid resistance may be studied with this equipment.

Data developed in laboratory have been compared with field data and the authors observed that the wear index increased as field performance improved. They concluded "that the laboratory tests can be used to prejudge performance prior to using an aggregate in the field."

SUPPLEMENTAL PRE-EVALUATION TOOLS

In addition to the mechanized laboratory test methods, there are at least three other laboratory techniques that have the reported potential for providing supplemental in-

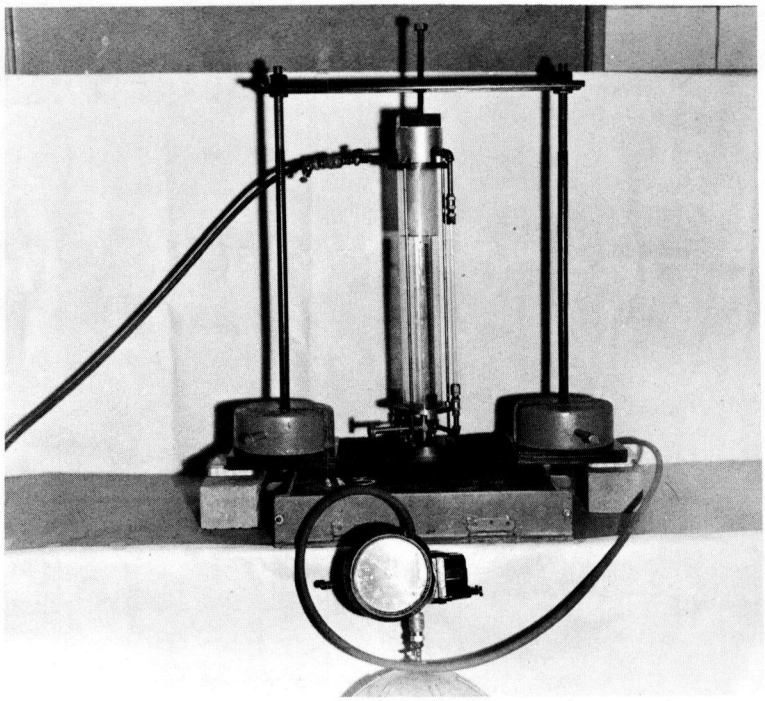

Figure 10. Tennessee water permeability device.

formation; these include the influence of sand-size siliceous particles based on the insoluble residue test, the influence of mineral content and nature of the total aggregate, and the influence of pavement permeability.

The work by Shupe and Lounsbury (3) along with that of Stutzenberger and Havens (4) related to studying the relationship between aggregate mineral content and susceptibility to polishing. Shupe and Lounsbury revealed that grain size and percent of calcium carbonate are useful factors in assessing the susceptibility of an aggregate to polishing under traffic wear. The research by Stutzenberger and Havens on specimens cut from blocks of sandstone and limestone points to the differences in coefficient of friction among these materials as influenced by coarse wear, differential hardness, cementitious material, and grain size. For example, the fine-grain dense stone polished more readily than the coarse-grain stone when subjected to Kentucky's testing techniques.

Gray (12), and later Gray and Renninger (13), reported that sand-size siliceous particles in an aggregate have an effect on skid resistance. The work reported by Balmer and Colley (11) and Goodwin (14) also supports this thesis. The procedures for determining the sand-size siliceous particles consist essentially of obtaining approximately 10,000 gm of the aggregate and soaking it in a dilute solution of hydrochloric acid until the acid has dissolved the carbonate minerals and there remains only a residue, which is filtered, washed, dried, and weighed. The residue is usually silt, clay, and siliceous material. The silt and clay, determined by washing the filtered solution over a 200-mesh sieve, are considered detrimental to skid resistance and are subtracted from the total residue to obtain the siliceous particle content. Balmer and Colley concluded that "the general trend of the data shows an increase in the wear index as the siliceous particle content increases."

The influence of pavement permeability, as affected by permeation of the water into the roadway surface and channelization over the roadway surface, is reported by Goodwin (14) as another measurable factor that can be used to aid in the pre-evaluation of pavement mixtures. The water permeability apparatus is shown in Figure 10. Typical

data reported show that as the pavement water permeability increases so does the resistance to the turning of the laboratory test tire.

Other researchers, for example, Hutchison at the University of Kentucky and the late Pete Kummer at Pennsylvania State University have studied permeability as well as surface texture. The research at the University of Kentucky (15) is being used to determine the dynamic permeability of pavement mixtures. The research is in the developmental stage but initial work has involved laboratory studies for determining the amount of water that can be drained vertically into a given pavement beneath a vehicle tire at various speeds of travel. The device essentially consists of forcing the water into the pavement by a shotgun blast and measuring the water flow by volumetric means. Future plans are to develop a device essentially for laboratory use that will discriminate between the effect of tire inflation pressure and tire speed as they relate to the hydrodynamic pressure that forces the water into the pavement.

SUMMARY

The laboratory methods discussed are only those that are truly for laboratory testing, except the machine used by California which may be used in both the field and laboratory. Other dual-purpose machines such as the British portable tester are not reviewed. There are also laboratory machines being used for testing of floor coverings that may have usefulness to the testing of pavement surfaces but such usefulness has not as yet been demonstrated. Undoubtedly other machines exist (for example, the one used by Jimenez of the University of Arizona, that is similar to Purdue's) which have not been developed sufficiently for reporting and are consequently unknown to the author.

Probably the greatest need in pre-evaluation of pavement mixtures is the correlation of laboratory results with field performance over a period of time.

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