LABORATORY AND FIELD TESTS CAN PREDICT LONG-TERM FIELD PERFORMANCE OF JOINT SEALANTS

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Laboratory tests used in the rubber industry can be valuable tools in predicting relative field performance of several generic highway joint sealants. When tested at high or low temperatures or after accelerated weathering, certain sealants show reduced ability to withstand joint movement caused by expansion and contraction of pavement sections. The ability of these sealants to withstand vertical deflections caused by heavy trucks on concrete pavement slabs is also affected. These test results may explain why some sealants have limited field success even though they may pass extension/compression tests run at room temperature on unaged material.

The extensive work now being done to restore the nation's highways testifies to the need for finding ways to lengthen highway life without incurring excessive maintenance costs. Much attention has been focused on problems of the joints between slabs of concrete highways. Failure of joint sealants allows water, deicing salts, and small stones to enter the joint. Water can destabilize slab foundations, deicing salts can corrode reinforcing steel, and small stones can produce local compression strains that disintegrate pavement slabs at the joints in hot weather.

It is well recognized that a joint sealant fails if it cannot withstand the normal opening and closing of the pavement joint produced when the slabs expand and contract with temperature changes. Less understood is the possibility of sealant failure caused by vertical shear in the joint, produced by deflection of the slabs under heavy truck traffic. Such deflections occur when a void exists under the joint, or when slabs curl because of a temperature difference between the top and bottom of the concrete.

The test conditions spelled out by Federal Specification TT-S-230C provide an objective means of comparing joint movement capability of three generic types of sealants under outdoor conditions. It covers movement in one plane, comparable to the opening and closing of a pavement joint caused by temperature changes.

An examination of manufacturers' literature shows that these generic types of sealants fall into well-defined ranges. As indicated in Table 1, the data cover only movement in a single direction, corresponding to the joint action produced by the expansion and contraction of concrete pavement slabs with temperature changes. However, a joint sealant's ability to withstand vertical shear movements is now recognized as very important also, since these movements are known to occur from deflections that are produced under traffic loads. [1,2,3]

Table 1.

Comparison of Thermal Joint-Movement Capability of Three Generic Sealants

Sealant Type	Horizontal Movement Capability, Percent
Polyurethanes	±12% to ±30%
Polysulfides	±12% to ±25%
Silicones	±12% to +100%/- 50%

Pavement deflections occur when traffic crosses a pavement joint that has a void beneath it or when the pavement slab is curled as a result of the temperature differential between the top and bottom of the concrete. The frequency, number, and size of vertical deflections depend on traffic volume, the weight of the individual vehicles, temperature, and pavement conditions.

The inability of a sealant to withstand multiple vertical shear movements may partly explain why some sealants pass laboratory extension/compression tests but have limited field success. Shear movements contribute to sealant failure if the sealant initially does not possess sufficient elastomeric properties or if it loses these properties. For example, a great increase in modulus indicates that the material has become stiffer, perhaps even rigid.

Rubber properties are generally different for each generic class of sealants and each sealant within a generic class. Changes in these properties occur in most sealants when they are tested at different temperatures and after simulated weathering. The magnitude of these changes provides information about the tendency of a particular sealant to fail under field situations similar to the test conditions.

For example, an effective joint sealant must maintain its elastomeric properties at low temperatures. By measuring modulus values at room and low temperatures, the effects of low temperature on the sealant's properties can be determined. If a significant increase in modulus is observed (i.e., if the sealant becomes significantly stiffer) at low temperature, its success as a sealant may be diminished.

Test Methods

Several laboratory tests used in the rubber industry can be also used by highway engineers to evaluate sealants. These tests are of two general types: Rubber property and performance tests.

Table 2 lists several tests that can be used to determine the physical properties of a specific sealant to differentiate one sealant from another sealant. Each test will determine only a specific rubber physical property (i.e. hardness, elongation), but collectively these tests provide the bases for sealant selection. For example, if the application requires a material to structurally bond two substrates together, a sealant with high durometer and modulus values (low elongation) would be recommended. For applications where the sealant must accommodate movement, a sealant with low durometer and modulus values (high elongation) would be preferred because of the greater flexibility.

Performance tests are used to simulate field conditions in the laboratory. The intent is to determine whether or not a sealant is capable of functioning reliably in a specific application. Accelerated weathering (ASTM C793-75, ASTM G53-77) and cyclic movement (ASTM C719-79, TT-5-230C) are examples of performance tests.

In this highway joint sealant study, properties of the sealants were measured at different temperatures and after simulated weathering in a weathering machine. Performance testing also included repeated flexing in a machine designed to simulate the vertical joint movement imposed on sealants under actual road conditions.

All of these tests except adhesion, movement and the vertical shear tests started with cured slabs of sealant approximately 0.318 cm (1/8 inch) thick. Durometer hardness tests are made directly on these slabs, with a direct reading instrument, in accordance with ASTM D 2240-81 test method. Tensile strength, elongation, and modulus measurements were carried out on dumbell-shaped test specimens die-cut from the cured slabs, as in ASTM D 412-83.

Adhesion, movement or vertical shear testing is performed with test joints created by gunning sealant between two concrete blocks. The sealant bead that is formed has dimensions of 1.27 cm (1/2 inch) wide x 1.27 cm (1/2 inch) thick x 5.08 cm (2 inches) long. The blocks were prepared by the method described in ASTM C-719-79 Sections 7.3.2 and 7.3.3.

Study Test Conditions

The testing results presented in this paper were limited to measuring the modulus rubber property and vertical shear capability. Rubber slabs and concrete test joints specimen were used in this study.

Both types of test specimens were allowed to stay at room temperature 24°C (75°F), 50 ±5% relative humidity for 30 days prior to the start of testing. ASTM D-412 was the method used to determine modulus. This method measures the force required to extend rubber tensile bars to a specified percent elongation. The only modification in this procedure was a reduction of the rate of pull from 50.8 cm (20 inches) per minute to 5.08 cm (2 inches) per minute. The slower pull rate allowed for a more accurate modulus measurement since a few aged samples failed quite rapidly at the higher pull rate.

The procedure is fairly simple. With the appropriate die, rubber tensile bars were cut from the cured rubber slabs. The modulus values of these slabs were determined with an Instron tensometer equipped with an environmental chamber having a temperature range of -68°C (-90°F) to 232°C (450°F). Conditions for this study were limited to the range of -37°C (-35°F) to 66°C (150°F).

Table 2. Rubber Industry Tests Useful in Joint Sealant Studies

Test	ASTM Test Method	Description
Durometer Hardness	D 2240-81	Measures the surface hardness of a rubbery material. The The higher the number, the harder the rubber.
Tensile Strength	D 412-83	Measures the strength at break of a rubbery material, expressed in kPa or psi.
Elongation (Ultimate Elongation)	D 412-83	The amount -- expressed in percent -- that the D 412 specimen may be stretched before it breaks.
Modulus	D 412-83	The amount of stress required to produce a given strain. The sample is pulled until it reaches a predetermined percent elongation, and the modulus is read in kPa or psi.
Adhesion (Bond Strength)		Measures the adhesion of a sealant to a substrate such as concrete. Test involves a simulated joint made with two concrete blocks, positioned to create a test joint. The joint is filled to specific dimensions with sealant is cured, and the joint is stretched to the minimum desired value of joint movement, plus an insurance factor.

All samples were allowed to equilibrate at the specified temperature before test measurements were made.

The shear tester used in this study (Figure 1), is a slight modification of one originally designed and built by the Georgia Department of Transportation, Research Branch. This device simulates the vertical pavement deflection caused by one truck crossing a joint.

The sample holder is divided into movable and nonmovable halves. The movable half provides positive and negative 0.318 cm (1/8 inch) deflections at 144 rpm through a cam attached to an electric motor. The 0.318 cm (1/8 inch) deflection two times larger than any deflections reported in field studies [2,3]. Thus the results provide a built-in safety factor.

In other words, a sealant that maintains its elastomeric properties and withstands these large deflections in the laboratory will have a higher probability of field success than a sealant that fails.

The 144 rpm speed simulates the rate of deflection caused by a truck approaching and crossing a joint at 88.5 km/h (55 mph), with a 9.14 m (30-foot) joint spacing.

Accelerated weathering was conducted according to ASTM G53-77. This procedure uses ultraviolet (UV) radiation from fluorescent lamps and condensation to simulate rain and dew. This method allows continuous operating time at significantly reduced cost compared to the traditional carbon-arc accelerated weathering test. The standard conditions with fluorescent lamps are four hours of UV exposure at 60°C (140°F) and four hours at 40°C (104°F). Samples including tensile bars and joint specimens--were placed in the weather simulator for a specified period of time, then allowed to stand at room conditions for 24 hours before modulus or shear tests began.

Accelerated weathering tests allow for quick simulation of the effects of natural weathering-especially the effects of sunlight, dew, and rain--on elastomeric materials. This type of testing simulates in a few months the effects of one, two, five, or more years of natural weathering on elastomeric materials.

Results and Discussion

Sealing highway and airport joints requires that the sealant remain elastomeric under a variety of climatic conditions. Many different joint sealants labeled as elastomeric or rubber have been used, but the field performance has been less than desired in many cases. The effect of environmental conditions on the elastomeric or rubber properties of some sealants is part of the reason for this less-than-desired performance.

Sealants will generally become more flexible as temperatures increase and less flexible as temperatures decrease. However, the temperatures at which these changes occur, and the magnitude of the changes, depend on the generic characteristics of the particular sealant being considered. Some sealants maintain their elastomeric properties over a wider temperature range than other sealants.

Table 3 shows the modulus values at 150% elongation for each sealant studied. Only one sample from each class was studied, and that sample was chosen to be representative of its class. The actual modulus values for other sealants may be different than the values shown, but the trends with weathering and temperature conditioning are likely to be similar within a given class.

Figure 1. Shear Testing Machine

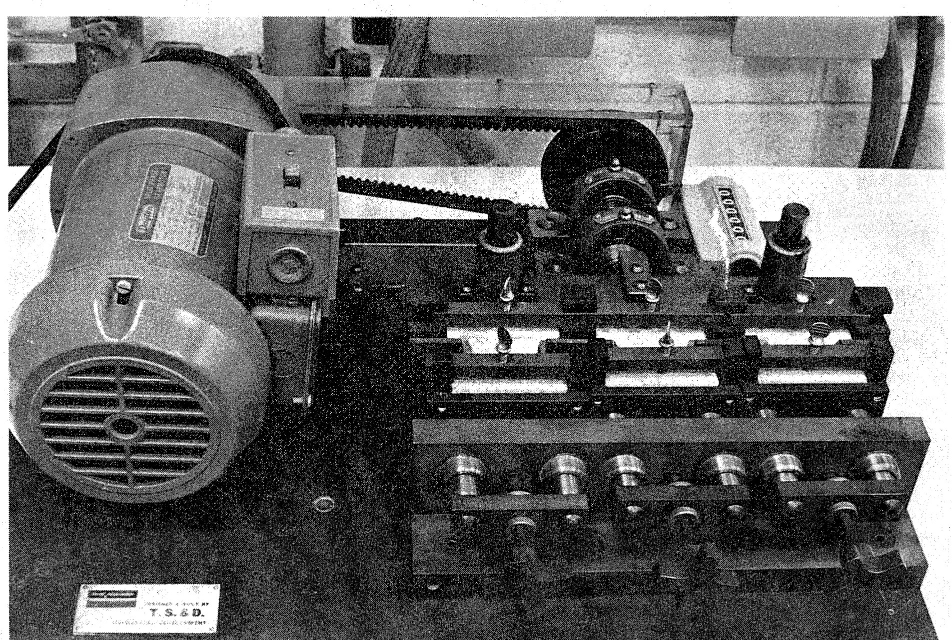


Table 3.

Initial Modulus Values of Various Sealants Measured At Room Temperature

Sealant Type	Typical Modulus Values At 150% Elongation	
	KPa	psi
Low-Modulus Silicones	179	26
Two-Component Organic Polymer	228	33
Polyurethane	469	68
Polysulfide	814	118

The effect of a specific temperature on elastomeric properties was determined by measuring the sealant's modulus at that temperature. (Figure 2) shows modulus changes, with temperature, for sealants shown in Table III.

Modulus at Temperature

The data in Figure 2 show that the modulus of each sealant changes as the temperature rises or falls. The size and nature of these changes depend upon the particular sealant and the temperature. The changes in modulus as a function of the temperature represent changes in the sealant's flexibility. As the temperature decreases, the modulus increases and the flexibility decreases for all sealants.

The rate of change in modulus was most noticeable in the -37°C (-35°F) to -18°C (0°F) range. For nonsilicone sealants the -18°C (0°F) to 10°C (50°F) range showed quite pronounced changes as well. However, only a small change was noted for the silicone in the -37°C (-35°F) to -29°C (-20°F) range.

The rate of modulus change varied with each sealant, and some changes were quite dramatic. Nevertheless, some degree of flexibility still existed at the cold temperatures for the best specimens, because they could still be stretched and tested.

As the sealant stiffens and loses flexibility with decreasing temperatures, more stress is placed on the sealant internally and on the bond line for a given amount of movement. These stresses ultimately can lead to failure, or at least contribute strongly to failure. Ideally, the sealant should be as flexible as possible. Good flexibility will minimize both the stresses that tend to tear the sealant apart and the stresses that tend to peel the sealant from the concrete at the bond line.

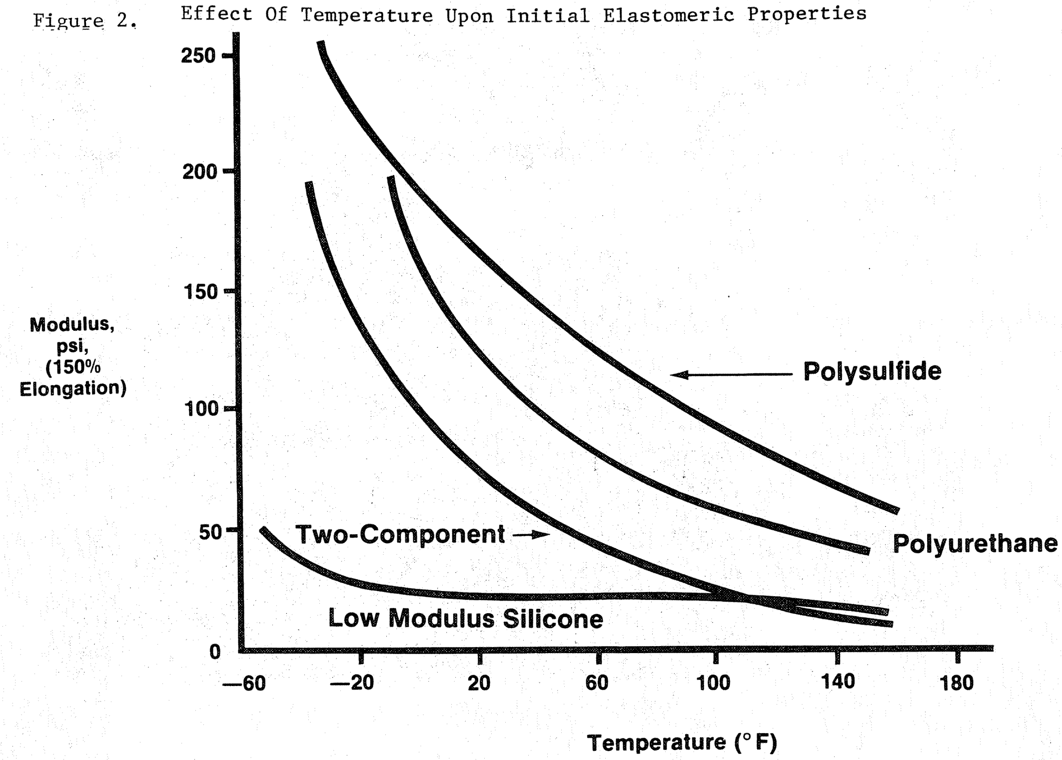
Generally, long-term field performance will depend upon the sealant's ability to maintain elastomeric properties over the temperature range expected at a particular location. Serious consideration should be given to the modulus properties of the sealant at the lowest temperature of expected use.

Modulus and Accelerated Weathering

Retention of elastomeric properties after weathering is as important to field performance as flexibility over a wide temperature range. The temperature range over which any sealant can remain elastomeric and perform effectively may be narrow, yet sufficient for a particular geographic location. However, if that sealant does not retain its elastomeric properties after weathering, its performance will be limited even within that original narrow temperature range.

(Figure 3) shows how the modulus value of each sealant is affected by accelerated weathering. The low-modulus silicones were almost unchanged in modulus value. All other sealants showed significant changes.

Figure 2. Effect Of Temperature Upon Initial Elastomeric Properties



The changes in these elastomers after weathering were of two types. The urethane became harder and increased in modulus. The polysulfide and the other two-part product showed a higher surface hardness (a higher Shore A durometer value), but showed a decrease in modulus of elasticity.

The 500 hours of accelerated weathering is not unduly severe when considering the performance of sealants for a range of U.S. locations. Some change in performance with weathering was expected for the nonsilicone sealants, but the amount of change that occurred was surprising.

Field performance will depend on the sealant's ability to remain elastomeric in spite of weathering. It is important to consider rates of change of elastomeric properties as well as absolute values of elastomeric properties. If weathering conditions are severe in the field location being considered, rapid rates of change may mean early failure of the joint sealant even though initial elastomeric properties may be adequate.

Vertical Shear Testing

The flexibility of an elastomeric sealant will determine its ability to withstand joint movements in highways caused by thermal changes (expansion and contraction) and traffic (vertical pavement deflections). Both movements can occur at the same time. Vertical deflections can occur when voids exist beneath the pavement and/or when the slab has curled due to a temperature differential between its top and bottom surfaces.4

Under traffic, these deflections are both positive and negative with respect to the adjacent slab, subjecting the sealant to a rapid shearing-type action.

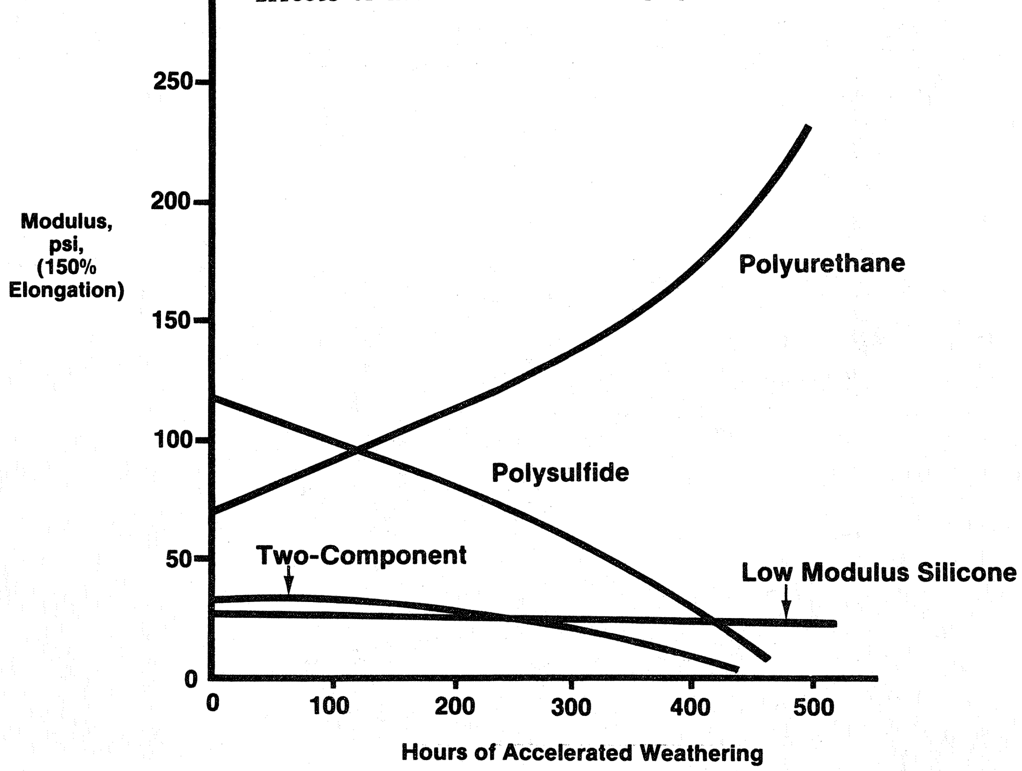
This shear force upon the sealant is most severe during the winter months when the joints are widest and the sealant is extended. Also, in winter, the slabs have greater freedom to move in relation to each other, since the slabs may have contracted enough to eliminate aggregate interlock.

The sealant must maintain enough flexibility to accommodate both the compression/extension forces produced by thermal movement of the slabs and the shearing forces caused by deflections of the slabs with respect to adjacent slabs.

The number of shear cycles a sealant is exposed to for a given period depends on traffic volume and pavement conditions. Only trucks, with their great axle weights, are believed to be significant in causing pavement deflection at the joints. The number of trucks per day on the interstate system varies greatly. For example, one highway section will have 3,000 trucks per day and another section of the same highway will have 15,000 trucks per day. The number of deflections can vary from 9000 - 45,000 per day, if the the trucks have three axles. The sealant must maintain its flexible elastomeric properties (show minimum modulus change), in order to withstand such a large number of deflections. The number and rate at which these deflections occur would indicate that the sealant's ability to withstand these shear forces can be as important--possibly more important--than its ability to withstand thermal movement.

The number of shear cycles a sealant can withstand initially and after accelerated weathering is another measure of its elastomeric properties. A sealant with good retention of elastomeric properties will withstand as many shear cycles after weathering as it does initially, when new. Each sealant shown in (Figure 4)

Figure 3. Effects Of Accelerated Weathering Upon Elastomeric Properties



has the ability to withstand cyclic shear when new. The number of shear cycles a sealant can withstand in these tests depends on the effects that accelerated weathering has upon the sealant's elastomeric properties.

Each sample in this test was continuously cycled under accelerated conditions of 25% sealant extension, 0.318 cm (1/8 inch) deflection at -28°C (-18°F), until 0.635 cm (1/4 inch) of adhesive and/or cohesive failure was observed.

All samples could withstand some shear stress. Except for the low-modulus silicone, all samples showed a pronounced reduction in their ability to withstand shear cycles as a function of accelerated weathering (Figure 4). Low-modulus silicones showed no signs of failure after one million cycles even after the full 500 hours of accelerating weathering.

Results in service have borne out this performance. A 22.9-cm (9-inch) concrete core was removed from I-75 in Georgia. It contained a five-year-old joint sealed with low-modulus silicone sealant. This roadway joint was then put into the test machine for one million more shear cycles. It showed no failure at the end of the combined field service and laboratory shear cycle testing.

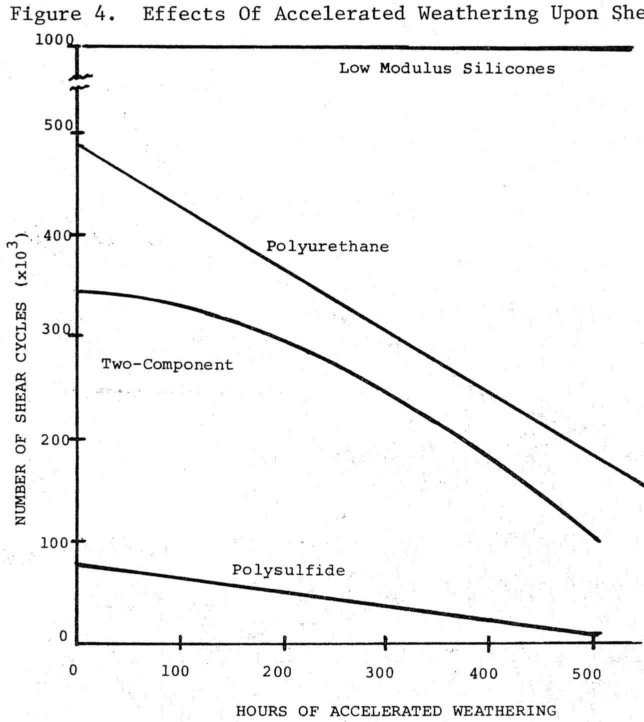
Temperature also affects the number of shear cycles that a sealant is able to withstand. Initial results show that as temperature increases, the observed number of shear cycles required to produce failure also increases. For example, an unaged polysulfide sealant exceeded 200,000 cycles without failure when tested at room temperature, but withstands less than 100,000 cycles at -28°C (-18°F). A similar observation was made for the other nonsilicone sealants. This shows the effect temperature has upon flexibility and is consistent with the modulus temperature curves in Figure 2.

This information provides some insight into why a particular sealant gives desired field performance in one geographic location, but less-than-desired performance in another location. With this understanding, the engineer can better select sealants for particular geographic locations and traffic densities, and obtain maximum field performance for those sealants.

Installation Requirements

In actual service, the performance of any elastomeric sealant depends on good joint design and proper joint preparation. The basic joint design considerations have been identified [5], which requires that the joint be wide enough to allow sufficient sealant to accommodate the anticipated movement, with a safety factor of two to three. Joints must be sawed deep enough to allow placement of a backer rod. Extra depth must be allowed in old pavements below the backer rod to accommodate "pumping" of old sealants. The backer rod serves two functions: first, it is made of a material that will not adhere to the sealant, preventing intolerable local stresses that would develop in the sealant if three-sided adhesion were permitted. Second, the backer rod shapes the sealant to give a cross-section that maximizes the bond area and minimizes stress on the adhesive bond when the joint widens. The top surface of the sealant is tooled to complete the desired hour-glass-shaped cross section. This step should also recess the sealant about 0.635 cm (1/4 inch) below the road surface, making it less subject to abrasion and tearing from traffic and road-maintenance equipment.

Figure 4. Effects Of Accelerated Weathering Upon Shear Cyclics



Proper installation procedures require that the concrete surfaces must be clean, firm, and dry. No sealant can be expected to bond to a contaminated surface. One acceptable procedure is to diamond-saw to remove old sealant from the joint walls, then sandblast. To remove dust from sandblasting, a high pressure oil and water free air blast should be used.

Conclusion

The information presented in this paper represents the results of initial investigations of the relationship between a sealant's elastomeric rubber property and its ability to withstand vertical shear caused by pavement deflections under traffic. Geographic location, time of year, traffic volume, and pavement condition determine the number, magnitude, and frequency of these deflections.

The success of a joint sealant depends on an understanding of the application requirements and on the selection of a sealant that meets those requirements.

Field performance of sealants used in concrete joints depends on the sealant's elastomeric rubber properties and on its ability to maintain these rubber properties over a long period of useful life.

Modulus testing, per ASTM D-412, is one method that can be used to measure a sealant's rubber properties. Modulus can be used to indicate changes in rubber properties that are caused by environmental conditions when testing is used in conjunction with accelerated weathering tests. This testing can be used to: (1) explain why certain classes of sealants, or sealants within a class, show different field performance in various geographic locations, and (2) establish minimum requirements for various sealants to meet application requirements. The highway engineer can use these laboratory tests to develop a better understanding of the relationship between laboratory results and actual field performance.

The initial results from this study indicate that vertical shear can contribute to failure of the sealant. The ability of the sealant to withstand this type of movement, initially and long-term, is related to the sealant's modulus at varying temperatures and the magnitude of modulus changes with aging.

The results indicate that all truly elastomeric sealants are capable of withstanding this type of movement for various periods of time. All samples tested showed a decrease in the number of shear cycles with simulated weathering or lower temperatures except for the low-modulus silicone. This decrease is attributable to the change in the sealant's rubber or modulus property with temperature or aging.

As previously mentioned, these preliminary results represent initial findings. Additional work is needed to study other variables (i.e. rate and duration of deflections). However, modulus testing provides a tool that is useful in measuring changes in rubber properties and in matching the sealant to the performance requirements.

Finally, the importance of proper installation procedures cannot be over emphasized. Although not discussed in great detail, all sealant selection and design considerations could be negated if proper procedures are not followed.

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