

# The Importance of Sealant Modulus to the Long-Term Performance of Concrete Highway Joint Sealants

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## ABSTRACT

Preliminary laboratory and field results are summarized that demonstrate the value of modulus testing in evaluating the initial and long-term elastomeric properties of several generic sealants. The effects of accelerated weathering on the elastomeric properties of these sealants are examined and an illustration is given of how changes in modulus can affect the sealant's ability to withstand vertical shear caused by pavement deflections under traffic. Laboratory results indicate that all samples tested have the ability to withstand some vertical shear. The number of shear cycles that a sample is able to withstand after accelerated aging has been related to changes in the sealant's modulus property. Of the samples studied, low-modulus silicones maintained their modulus property and withstood the largest number of shear cycles. Test procedures and methods used in this study are described.

Considerable effort currently is focused on the restoration of U.S. highways. Diamond grinding and slab stabilization are among the techniques used to rehabilitate concrete pavements; joint resealing plays a key role in the total restoration process.

The role of the joint sealant is to prevent problems associated with water, incompressibles (e.g., dirt, small stones), and deicing chemicals that enter the joint from the surface. This type of infiltration results in erosion of pavement foundation, concrete spalling, and corrosion of embedded metals. If there is no surface seal or if the seal has failed, these problems associated with infiltration will be accelerated.

The joint sealant generally represents the smallest part of a new construction or rehabilitation project, but the performance demands placed on it are enormous. Selecting the correct sealant for the application thus is critical. Several tests can help the highway engineer in his evaluations. These tests are well known in the rubber industry, but many highway engineers may not be aware of them or may not fully appreciate the value of the information they provide.

As a result, tests that can be used to demonstrate the sealant's ability to maintain its elastomeric properties are often not used. With long-term sealant performance being the goal for new construction and rehabilitation, tests that can provide information regarding the elastomeric properties of generic sealants should be more closely examined.

Modulus testing in accordance with ASTM D-412 is one rubber test method that can be used as a tool to study a sealant's rubber or elastomeric characteristics. By definition, modulus is the force required to extend a rubber tensile bar to a specified percent elongation. This modulus value, at a specific elongation, will generally be different for each generic class of sealant:

Sealant Studied	Typical Modulus Value at 150 Percent Elongation (psi)
Low-modulus silicone	26
Two-component organic polymer	33
Polyurethane	68
Polysulfide	118

Regardless of the generic class, significant changes in the modulus values during testing can provide information about that particular sealant under similar field conditions. For example, an effective joint sealant must maintain its elastomeric properties at low temperatures. By measuring modulus values at room and low temperature, the effects of low temperature on the sealant's properties can be determined. If a significant increase in modulus is observed (i.e., the sealant becomes significantly stiffer) at low temperature, its success as a sealant may be diminished. The ability of a sealant to maintain its elastomeric properties can be determined by conducting accelerated tests such as weathering and heat aging.

Significant positive or negative changes in modulus values would indicate that elastomeric properties are changing, and actual field performance will depend on the extent of these changes. Thus modulus values obtained from various tests can provide information regarding the sealant's basic generic elastomeric properties; these properties ultimately control the sealant's long-term field performance.

In the field, the sealant must maintain its elastomeric properties as long as possible to accommodate the movement associated with concrete pavements. Horizontal movement (thermal expansion and contraction) capability is a well-recognized criterion for a joint sealant. But in the last few years studies have shown that the sealant is subjected to vertical shear movements also (resulting from pavement deflections) (1-3). These pavement deflections occur when traffic crosses a jointed pavement beneath which there are voids or when the pavement has curled as a result of the temperature differential between the top and the bottom. The frequency, number, and size of these vertical deflections that occur will depend on traffic volume (especially truck traffic), temperature, and pavement conditions. The ability to withstand vertical shear may partly explain why some sealants that pass laboratory extension and compression tests have limited field success. If the sealant does not possess sufficient elastomeric properties initially or it loses its elastomeric properties (i.e., there is a significant modulus change), these shear movements can contribute to sealant failure

(adhesive or cohesive or both). Thus, the ability to possess and maintain rubber properties becomes extremely important.

How temperature, modulus, and the retention of modulus after accelerated weathering affect the ability of several sealants to withstand vertical shear is examined. The test methods and equipment are also discussed.

#### TEST METHODS, PROCEDURES, AND EQUIPMENT

Two types of sealant test specimens were prepared for this study. The first type consisted of rubber slabs approximately 1/8 in. thick. These rubber slabs were used to determine modulus values. The second type was a test joint where the sealant bead between two concrete blocks was 1/2 in. wide x 1/2 in. thick x 2 in. long. The blocks were prepared according to ASTM procedures. These test joints were used for shear testing. Both types of test specimens were allowed to stay at room temperature (75°F, 50 ± 5 percent relative humidity) for 30 days before 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. With the appropriate die, rubber tensile bars were cut from the cured rubber slabs. The modulus values were determined on an Instron tensiometer equipped with an environmental chamber. Figure 1 shows the inside of the test chamber with a test specimen between the gaps. This chamber can be operated above and below ambient conditions (-90 to 450°F). The study conditions were limited to -35 to 150°F. Measuring rubber properties (i.e., modulus)

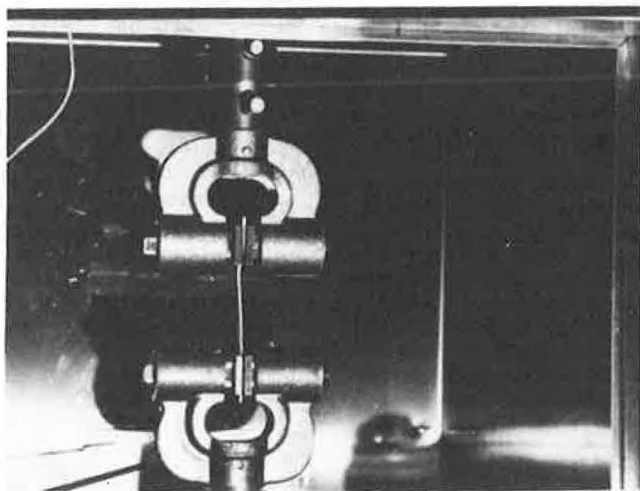


FIGURE 1 Environmental chamber with test specimen.

at various temperatures allows one to determine how temperature affects elastomeric properties and ultimate field performance. For example, at low temperature the sealant may become too stiff to accommodate movement. Or at high temperatures, the sealant may be too soft to reject stones. All samples were allowed to equilibrate at the specified temperature before the start of modulus testing. The only modification in the ASTM D-412 procedure was to reduce the rate of pull from 20 in./min to 2 in./min. The slower pull rate allowed for a more accurate modulus

measurement because a few aged samples failed quite rapidly at the higher pull rate.

The shear tester used in this study (Figure 2) is a slight modification of one originally designed and built by the Research Branch of the Georgia Department of Transportation. This equipment simulates the vertical pavement deflection caused by one truck crossing a joint. The sample holder is divided into movable and unmovable halves. The movable half provides positive and negative 1/8-in. deflections at 144 rpm through an off-center cam attached to an electric motor. The 1/8 in. causes more deflection than that reported in field studies (2,3) but does provide a safety factor (2,4). In other words, a sealant that can maintain its elastomeric properties and withstand a large deflection in the laboratory will have a higher probability of field success. The 144-rpm deflection simulates the rate of deflection caused by a truck approaching and crossing a joint at 55 mph, with joint spacing of 30 ft.

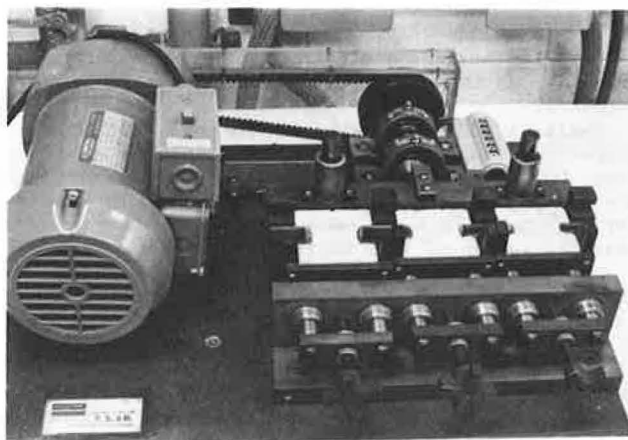


FIGURE 2 Shear tester.

Accelerated weathering tests allow one to simulate quickly the effects of natural weathering [ultraviolet (UV) exposure, rain] on various materials in the laboratory rather than relying solely on long-term outdoor testing. This type of testing can simulate in only a few months the effects of 1, 2, or 5 years or more of natural weathering on elastomeric materials.

Accelerated weathering was conducted according to ASTM G53-77 (Figure 3). This procedure uses UV radiation from fluorescent lamps and condensation to simulate rain and dew. In contrast to the traditional carbon-arc-accelerated weathering test, this method allows longer operating time at significantly reduced cost. The standard conditions are 4 hr of UV exposure at 60°C and 4 hr of condensation at 40°C. Samples (tensile bars and joint specimen) were placed in the weatherometer for the specified time and then allowed to stand at room conditions for 24 hr before modulus or shear testing was started.

#### RESULTS AND DISCUSSION

Sealing highway and airport joints requires that the sealant remain elastomeric under a variety of climatic conditions. Over the years, many different materials labeled as elastomeric or rubber joint sealants have been used, but the field performance has been less than desirable for truly elastomeric materials. The effect that environmental conditions

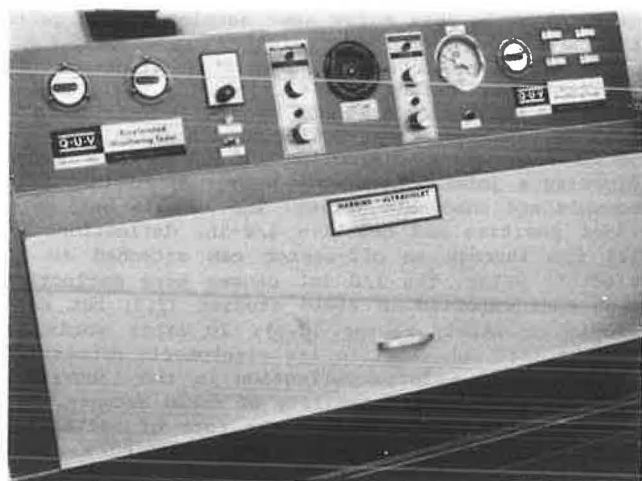


FIGURE 3 Accelerated weathering machine.

have on the sealant's elastomer or rubber properties is part of the reason for this undesirable performance.

Sealants will generally become more flexible as temperature increases and less flexible as temperature decreases. However, the temperature range and the extent to which significant changes in elastomeric properties will occur depend on the generic characteristics of that particular sealant.

The modulus values at 150 percent elongation for each sealant studied were tabulated earlier. Only one sample from each class was studied, and that sample is believed to be representative of that class. For other specific sealants in a given class, the actual modulus values may be different from the values shown. The effect that a specific temperature has on the elastomeric properties can be determined by measuring the sealant's modulus at that temperature by using the representative sealants shown earlier.

#### Modulus as a Function of Temperature

The data in Figure 4 show that the modulus of each sealant changes with temperature. The size and nature

of these changes are dependent on the particular sealant and the temperature. The changes in modulus as a function of temperature represent changes in the sealant's flexibility. As temperature decreases, the modulus increases and flexibility decreases for all sealants. The rate of change was most pronounced in the range -35 to 0°F. For nonsilicone, the range 0 to 50°F showed quite pronounced changes as well. The only significant change noted for the silicone was in the range -35 to -20°F. Although the rate of modulus change varies with each sealant, and some were quite dramatic, some degree of flexibility still exists at the low temperatures, because the best specimens could still be stretched and tested.

From the viewpoint of application, the change in flexibility with decreasing temperatures translates into an increase in the sealant's cohesive character. With increased cohesion, more stress is placed on the sealant internally and on the bond line. These stresses ultimately can lead or significantly contribute to failure. Ideally, these forces should be as small as possible to prevent stress buildup. Thus, some aspects of the long-term field performance will depend on the sealant's capability to maintain elastomeric properties over the temperature range expected at a particular location. Serious consideration should be given to low-temperature effects if the sealant is to be used under low temperatures.

#### Modulus as a Function of Accelerated Weathering

Retention of elastomeric properties after weathering is as important to field performance as initial wide-temperature flexibility. The temperature range in which any sealant can remain elastomeric and perform effectively may be narrow but sufficient for a particular geographic location. However, if on weathering that particular sealant does not retain those elastomeric properties, then performance, even over a narrow temperature range, will be limited. Figure 5 shows how the modulus value of each sealant is affected by accelerated weathering. As shown, only the low-modulus silicones showed virtually no change in modulus value, which illustrates the retention of elastomeric properties. The other elastomerics showed two types of behavior. The polyurethane became harder and increased in modulus of elasticity. The polysulfide and other two-part

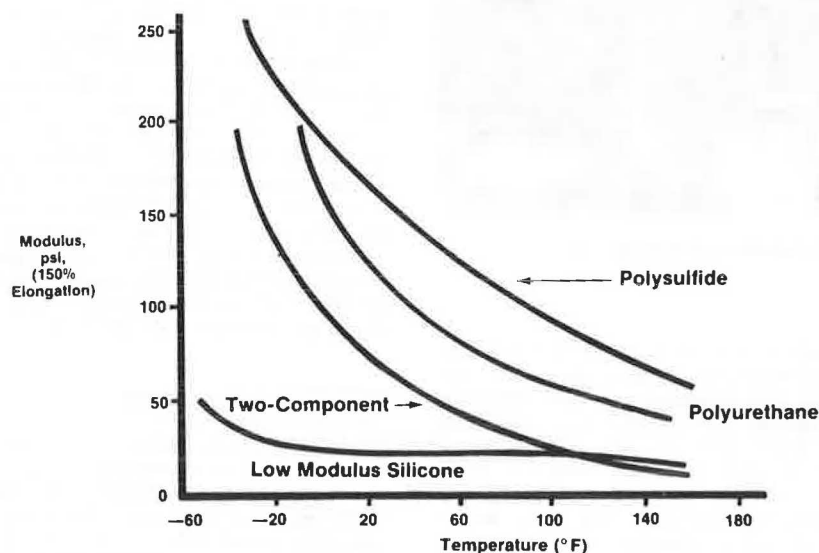


FIGURE 4 Effect of temperature on initial elastomeric properties.



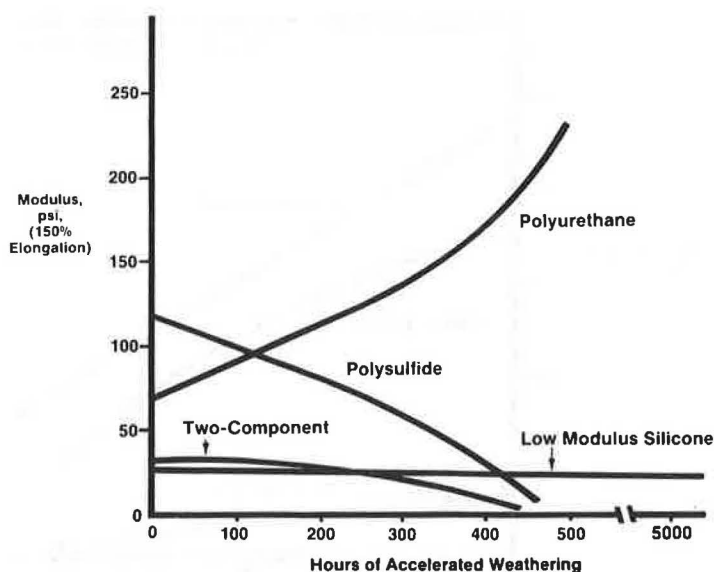


FIGURE 5 Effect of accelerated weathering on elastomeric properties.

product became harder when tested to shore A but actually showed a decrease in modulus of elasticity as a function of weathering. (The authors make no effort to explain the results with the sealants studied, only to report them.) The 500-hr accelerated weathering is not considered unduly severe when sealants for most U.S. locations are considered. Field performance will depend on the sealant's ability to remain elastomeric under the weathering conditions expected. Because weathering conditions vary the rates of change as well as the absolute value of the elastomeric properties, curves like those generated here should be important when a sealant is considered for a given location.

#### Vertical Shear Testing

Flexible elastomeric properties will control a sealant's ability to withstand joint movements in the field caused by thermal changes (expansion and contraction) and traffic (vertical pavement deflections). Depending on field conditions, both movements can occur at the same time. In the case of vertical deflections, these can occur because of small voids that exist beneath the pavement or because of the curling due to a temperature differential or both. Under traffic, these deflections will be positive and negative and in turn will subject the sealant to a rapid shearing action. This shear force on the sealant is expected to be the most severe during the winter months when the joints are widest (sealant extended) and pavement slabs can move independently (i.e., no load transfer device or no aggregate interlock of slabs). Because this shearing movement is in addition to the thermal movement, the sealant must maintain flexibility to accommodate both types of movement. The number of shear cycles that a sealant is exposed to for a given period will depend on traffic volume and pavement conditions. Because of weight, only truck traffic is believed to be significant in causing pavement deflection at the joints. The number of trucks per day on the Interstate system varies greatly, but many officials believe that 3,000 trucks per day is representative of typical truck volume on the average roadway. With each truck having three axles, this would expose the sealant to 9,000 deflections per day or 810,000 deflections for a

3-month winter period. In order to withstand such a large number of deflections, the sealant must maintain its flexible elastomeric properties (i.e., show minimal modulus change). In addition, 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 as--possibly more important than--the ability to withstand thermal movement.

The number of shear cycles that a sealant can withstand initially and after accelerated weathering is another measure of its elastomeric properties. If a sealant maintains its elastomeric property after accelerated weathering, no change in the number of shear cycles would be expected. As shown in Figure 6, each sealant has the ability to withstand cyclic shear.

Under accelerated conditions of 25 percent sealant extension,  $\pm 1/8$ -in. deflection at  $-18^{\circ}\text{F}$ , each sample was continuously cycled until  $1/4$  in. of adhesive or cohesive failure or both was observed. All samples had the ability to withstand some shear stress. Except for the low-modulus silicone, all samples showed a reduction in their shear movement capability as a function of accelerated weathering. Low-modulus silicones showed no signs of failure after 1,000,000 cycles. In addition, a 9-in. concrete core, which was removed from I-75 in Georgia containing a 5-year-old, low-modulus silicone sealed joint, was put into the test machine for 1,000,000 more shear cycles and showed no failure.

Temperature will also affect the number of shear cycles that a sealant is able to withstand. Although not studied in detail, initial results show that as temperature increases, the observed number of shear cycles also increases. For example, an unaged polysulfide sealant exceeded 200,000 cycles without failure when tested at room temperature but less than 100,000 cycles at  $-18^{\circ}\text{F}$ . A similar observation was made for the other nonsilicone sealants. This shows the effect temperature has on flexibility and is consistent with the curves of modulus versus temperature in Figure 4. This information provides some insight into why a particular sealant may give the desired field performance in another location. With this understanding, the engineer can better select sealants suited for a particular geographic location and traffic density and thus obtain maximum field performance for that sealant.

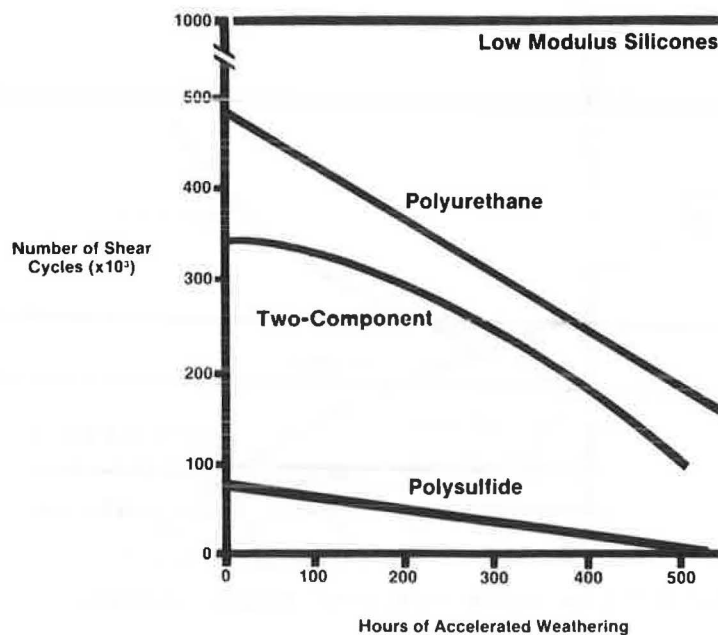


FIGURE 6 Effect of accelerated weathering on shear cycles.

#### CONCLUSION

The information presented in this paper represents some of the initial investigations into studying 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 will determine the number, size, and frequency at which these deflections will occur. The sealant's success will depend on a better understanding of the application requirements and selection of a sealant that can meet those requirements.

Field performance of sealants used in concrete joints depends on the sealant's elastomeric rubber properties and the ability to maintain those rubber properties. As the ability to maintain those properties increases, longer useful life will be the expected field performance. Modulus testing according to ASTM D-412 is one method that can be used to measure a sealant's rubber properties. When used in conjunction with accelerated tests (i.e., weathering), modulus can indicate changes in rubber properties that are caused by environmental conditions. Thus, the engineer can use these laboratory tests to develop a better relationship between actual field performance and laboratory results. This testing could be used to explain why certain classes of sealants, or sealants within a class, show differing field performance in various geographic locations and establish minimum requirements for various sealants to meet application requirements.

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 over the long term is related to the sealant's modulus at various temperatures and how the 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. Except for low-modulus silicon, all samples tested showed a decrease in the number of shear cycles. This decrease has been attributed to a change in the sealant's rubber or modulus property with changes in temperature or aging.

As previously mentioned, the preliminary results represent the initial findings. Additional work is needed to study other variables (e.g., rate and duration of deflections). But modulus testing provides a tool by which to monitor changes in rubber properties and then match the sealant with the performance requirements.

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