INVESTIGATION INTO THE PERFORMANCE OF RIGID PAVEMENT JOINTS AND SEALANTS

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INTRODUCTION

The first portland cement concrete pavement in the United States was laid in the 1890's, but was soon abandoned because of problems with defects and difficulty of maintenance. Most of the problems centered around cracks and joints as is seen from the following 1916 quote.[1]

> "Cracks and Joints. Again it seems pretty generally agreed that concrete roadways are liable to objectionable cracking under the influence of changes in temperature and in the conditions regarding moisture present. After being placed, the wet concrete shrinks considerably in setting and drying and this change of volume produces cracks in the surface. These cracks form points of weakness and foci of deterioration more or less serious according to their distribution and concentration. The effort is usually made to concentrate them in regularly occurring joints and these are often predeterminedly built in place with cumbersome iron or steel plates, which themselves are objectionable to traffic. These expansion joints increase in obnoxiousness as the road gets older and wears down and ultimately, in order to relieve this feature, if for no other reason, the coating of the whole road with a bituminous or other surface or pavement is necessary. If these expansion joints are not provided in the first place, the concrete roadway surface may develop cracks irregularly under alternate wetness and dryness or heat and cold, and these cracks break away on their edges and ultimately develop into objectionable places in the surface. Apparently the only remedy is to cover the entire surface with a carpet or pavement. The concrete roadway then becomes a concrete foundation, and if it can be foreseen, that such an end is probably to result within a limited time, reasons of economy demand its careful consideration before reaching a decision to attempt the concrete roadway construction in the first place."

Contraction joints in concrete pavement are still a problem today. Unsealed joints are a major contributor to concrete pavement deterioration. The entrance of surface water into the pavement system through the joints can cause faulting of joints, loss of base material, eventual slab cracking and reduced rideability.

The Georgia Department of Transportation recently completed a five year study into the area of joints and sealants for rigid pavements. Thirty-two test sections were constructed between the fall of 1970 and the spring of 1971 on I-20 east of Atlanta. The test area included joint spacings of 20 feet and 30 feet both at normal and skewed angles to the centerline and a total of eight (8) joint sealant. The joint sealants consisted of two polysulfide two-component polymers, two (2) polyurethane two-component polymers, two (2) hot-applied rubberized asphalt sealants, both open and closed cell neoprene sealants and a hot-applied polyvinylchloride (PVC) sealant. With the exception of the PVC sealant which was only a limited installation the test sections totaled 20,000 feet of 24 foot pavement for each sealant.

The installation of the various joint sealants was carefully supervised during construction to minimize reduced performance due to improper installation. Evaluations of the performance of the joint variables and sealants were made during the duration of the study period. Movement measurements of the sealant performance and joint movement were made. The latest shape factors and joint design theories for joint sealants were used. Sealant manufacturers recommended joint designs for the use of their material.

Based on the experience gained from the research project on I-20 the following recommendations were made.

1. That open cell neoprene not be specified for joints without dowels.
2. That consideration be given to sealing shoulder joint with low modulus silicone.
3. That polysulfide and polyurethane not be used to seal rigid pavement contraction joints unless the shape factor is changed from the approximate 1:1 used on the research.
4. That closed cell neoprene be included in the specifications and specified on some projects.
5. That consideration be given to delaying sealing until shoulder construction and grassing is complete.

HOW WATERTIGHT MUST A SEAL BE TO BE EFFECTIVE?

Faulting measurements have been made on the high side of super-elevated curves and at various locations on a plus and minus grade. Faulting is present at all these locations and attempts to correlate the magnitude of faulting with these variables have failed. Apparently a surplus of water is required for the fautling process and sufficient water is present in the vicinity of all joints during a rain. Since there is no significant difference in the faulting with respect to slope or grade, it appears that adequate water to transport material abraided from the base is only present during and immediately after a rain. Voids in the shoulder adjacent transverse joints are often more pronounced at positions on grades where the flow or movement of water is greatest.

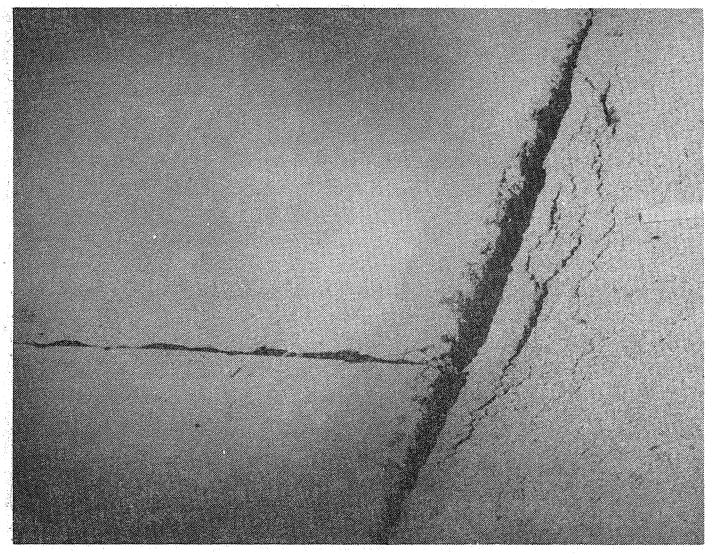


Figure 1
Typical Void at Shoulder Joint and Transverse Joint

Some locations on long steep grades appear to have worse faulting. However, variation in measurements made with the faultmeter precludes a definite conclusion to this effect.

Transverse joints are effectively sealed in some sealant sections on the I-20 research project. However, no measurable difference in pavement performance is obtained by the roadmeter, faultmeter or measuring points. If sealing of transverse joints alone can prevent faulting and increase pavement performance some obvious or measurable difference in pavement performance should exist when pavement begins to be of a measurable magnitude. Therefore, transverse joints must be watertight and water entering shoulder joints must be prevented or possibly rapidly removed.

FACTORS WHICH RELATE TO STRESSES IN JOINT SEALANTS

The effect of the shape factor on the degree of stress present in a field molded sealant is well known. Also, the need for a bond breaker to prevent small portions of the sealant section from being overstressed has been recognized. However, there are other

factors which induce stresses in joint sealants which may cause early failure of the joint sealant.

Most sealants experience considerable shrinkage upon curing. This is apparent from the parabolic shape the sealant assumes in the joints or in the test blocks. In the test blocks the shape factor is normally 4:1 (1/2 x 2 inches) (1.27 x 5.08 cm.) and the parabolic shape is very pronounced. For this reason the molds are built up to mold the specimen. This fact is also apparent from placing hot pour sealant in pails. The sealant assumes a concave parabolic shape upon cooling.

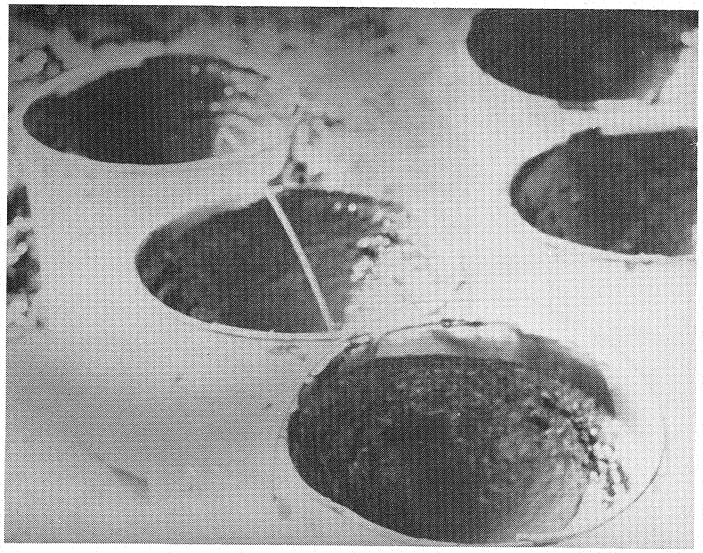


Figure 2
Shrinkage of hot pour sealant is apparent when the sealant cools in pails.

Many joints are not relieved at the time they are sealed. If a joint is not relief cracked at the time it is sealed, tension in the sealant results when the joint is relieved. It is common for a relief crack to be 1/16 inch (1.59 mm.) wide. This represents 25 to 50% of the extension movement most contraction joints are designed to accommodate. Many spalls and therefore adhesion failures are evidenced by a bulge in the sealant adjacent the spall.

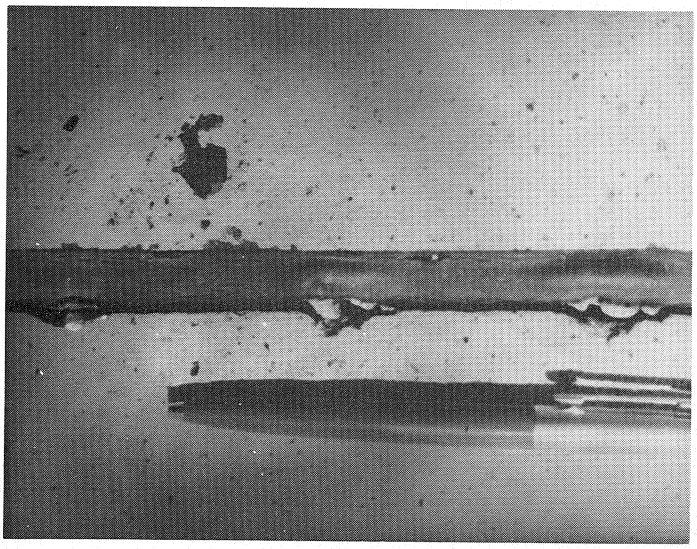


Figure 3
The bulges in the sealant at the spalls are caused by a relief of tensile stress in the sealant. This is a polysulfide rubber.

This bulge is caused by relief of tensile stress in the sealant and shows that the remainder of the sealant is in tension. Therefore most field molded sealants applied in very hot weather when the relief cracks are tightly closed by expansion are always in tension. This is undesirable because it taxes the adhesive ability of the sealant. This is not necessarily true of silicone sealants which have little or no shrinkage.

Conditions can also exist at the time a joint is sealed which will cause the sealant to be highly compressed at some stage of its performance. The first joints to relief crack can become very wide because they are contracting for several slabs instead of one.

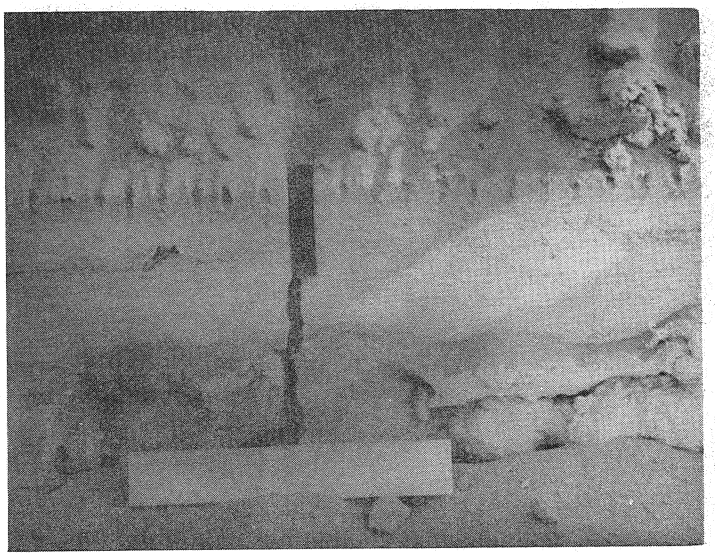


Figure 4
A joint having a very wide relief crack. Contracting for several slabs crack open approximately 3/16 inch (4.76 mm.).

Because the volume of the sealant remains relatively constant when compressed, sealant placed in these wide open joints will be highly compressed and often extruded from the joint in hot weather. Sometimes, every third joint has more sealant extruded on the pavement. This extrusion indicates that every third joint was relief cracked and contracting for three slabs instead of one when it was sealed. Although they can withstand enormous compressive forces, preformed neoprene compression seals can be compressed in this manner to the extent that their ability to recover is impaired. Joints that are relieved and contracted when widened should be sawed with wider saw blade combinations.

Faulting is the vertical displacement of one slab with respect to another. Faulting can cause a shear type stress to be induced in the sealant section. In field molded sealants this displacement serves to increase the tensile stresses in the fibers of the sealant section. On plain concrete faulting can potentially double the strain on a joint sealant. Therefore, faulting must be considered in sealant design. Theoretically if the entry of water to the plane between the base and the paving can be prevented faulting can not develop. However, it is apparent that sufficient water enters through the shoulder joint to support faulting. Preformed open cell seals cannot normally accommodate faulting in excess of 1/8 inch (3.18 mm.) without slipping on the joint face. They are not designed for a shearing type movement and the greater the degree of compression the less shearing movement can be accommodated. If faulting can be prevented by sealing, the need for costly load transfer devices can be eliminated. If faulting can not be prevented, transverse joint sealing is only of value to prevent the entry of incompressibles. Sealing of transverse joint alone has not prevented faulting in the past. When faulting, loss of recovery, or lack of adhesion occurs sand particles become trapped between the seal and the joint face (Figure 5 next page). This normally begins on the portion of the joint adjacent to the outside pavement edge.

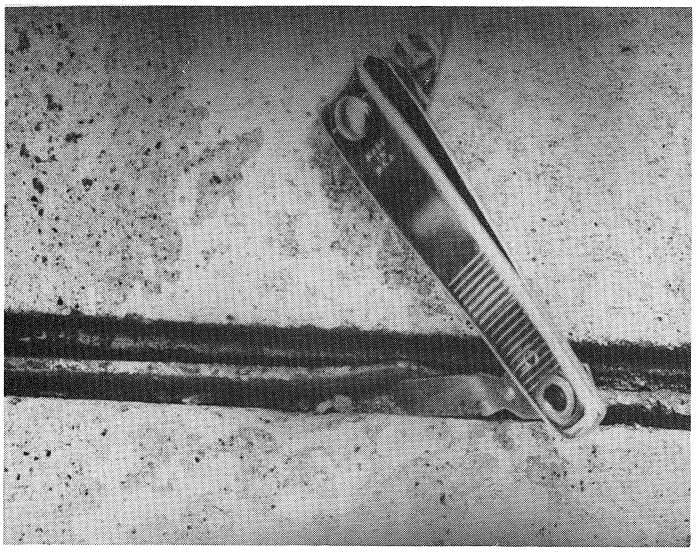


Figure 5
Sand trapped between seal and joint face.

SILICONE SEALANTS FOR HIGHWAY APPLICATIONS

Silicone sealants have not been promoted as sealants for highway contraction joints. The main objections have been that they are too expensive and did not possess adequate adhesion without the use of a primer and adhesion to concrete is poor. Among the disadvantages reported by consumers was the fact that the sealant picks up dirt and has joint width limitations.[2]

Also, a definite disadvantage is the fact that several cycles of joint movement occurs before the sealant is completely cured. Indications are that the material can withstand this movement in an uncured state without failure.

The major advantages of the silicone as a rigid pavement contraction joint sealant are the following:

1. Properties are virtually unchanged over a wide range of temperatures both in cured and uncured states.
2. It is available as a one component sealant.
3. Sealants are available that do not require primer on concrete surfaces and adequate adhesion is possible because extremely low modulus is retained in cold weather. This is not true of the mastic sealants which have relatively high modulus in cold weather when extension is greatest.
4. Unlike polysulfide, polyurethane and hot pour sealants silicones do not shrink upon curing. Shrinkage can immediately induce tension in sealants.
5. Silicone elastomers are somewhat inert and therefore exhibit excellent weathering characteristics.
6. A perfect joint is not required. Silicone can seal a small spall. Preformed seals cannot (Figure 6 next page).

The silicone reported by John P. Cook[2] as having an adhesive strength too low for its tensile strength was a material having a typical shore hardness of 35 and a tensile strength of 400 psi. The low modulus material discussed in the following paragraphs of this report has a shore A hardness when cured about 20 and an ultimate tensile strength of 100 psi. The adhesive strength developed on concrete without primer by the low modulus material appears to be adequate to insure acceptable performance in rigid pavement contraction joint. Also, adhesion to asphaltic concrete appears to be adequate in one limited field installation on I-85.

The increased cost of polysulfides, polyurethanes and preformed neoprene has made silicone sealants much more competitive. Also, silicones are not dependent on the availability of petroleum. A typical roadway joint approximately 3/8 in. by 1/4 inch

(9.52 x 6.35 mm.) including waste (125 linear feet/gallon or 10.07 meters/liter) cost about 20 cents per foot (66 cents per meter) for material. This is roughly one half the cost of open cell neoprene seal per foot and about the same price as closed cell neoprene.

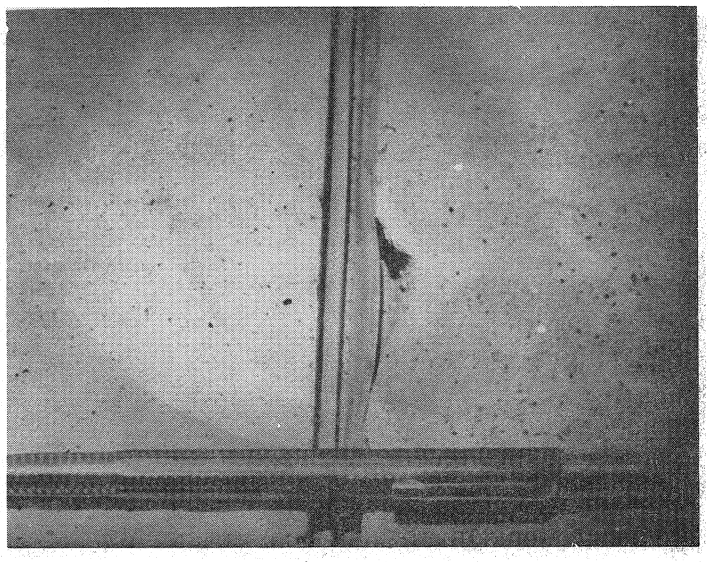


Figure 6
Preformed seals cannot seal a small spall.

Weatherometer Tests

As of July 1976 a specimen of Dow 790 silicone has been in the weatherometer over 5300 hours the hardness has not changed appreciably. No visible deterioration other than superficial staining from the metal plate is evident.

Bond Tests

Specimen were prepared with sealant width 1/2 inch, 1.27 cm.; depth 1/4 inch, .64 cm.; 2 inch, 5.08 cm. long. Standard concrete blocks were used. The results were as follows:

Cure	Length of Extension for Failure
24 hrs.; Dry	9 inches; 22.9 cm.
24 hrs.; Wet	5 inches; 12.7 cm.
72 hrs.; Dry	6 1/4 inches; 15.9 cm.
72 hrs.; Wet	6 inches; 15.2 cm.

When the cure is incomplete, extension required for failure may be greater and the failure is usually cohesive. Cured specimen are stronger, extension is less, and the failure is usually adhesive.

INCORPORATING OF DEBRIS INTO UNCURED MATERIAL

To determine the curing time required for sufficient film to form and prevent contamination by debris specimen were cured at varying times and temperatures in 8 ounce (2.36.6 cc) ointment cups having a diameter of 3 inches (7.62 cm.). The silicone was covered with 1 inch (2.54 cm.) of moist concrete sand and the amount of sand sticking to the 3 inch (7.62 cm.) diameter surface is tabulated below:

Temperature	50 min.	3 hr. 40 min.	7 hr. 40 min.
38°F	1.7 gm.	1.0 gm.	1.5 gm.
77°F	1.4 gm.	0.6 gm.	1.1 gm.
140°F	2.8 gm.	1.5 gm.	1.9 gm.

It appears that if the material is properly recessed contamination before cure will not be a problem and traffic can be allowed on a resealed road after about 1 hour.

Specifications

Like other elastomers standard tests to establish physical properties are the following:

1. tensile strength
2. elongation at break
3. modulus
4. hardness
5. permanent set after stressing in tension or compression
6. resilience
7. retention of properties
8. ozone resistance
9. resistance to weathering
10. abrasion
11. tear strength
12. adhesion in peel
13. staining
14. bond strength
15. tack free time

Most of the above tests do not simulate in any way the performance of silicone as a joint sealant. Also, most of these tests are not practical as acceptance tests of the material on a project basis.

Tensile Strength, Tear Strength, Elongation and Modulus

The ultimate tensile strength of low modulus silicone is about 100 psi (700 kPa.). However, silicones are available which have tensile strengths of 400 psi (2800 kPa.) or more. It is very important to have material of low modulus and tensile strength, but it is very difficult to establish a range of acceptable values for the following reasons:

1. The specimen are usually very thin and the area is difficult to determine accurately because the material is very soft.
2. The degree of cure greatly influences this property and the cure is dependent upon temperature and humidity and is very slow.
3. The very low forces required are difficult to measure accurately.

Hardness

The hardness appears to be a good indication whether or not the material is a low modulus material. The hardness, shore A, of the low modulus material is about 15 after 7 days cure. Some other silicones have a hardness shore A of 35.

Permanent Set

Silicones have excellent recovery from low levels of tensile and compressive stresses. However, it would be difficult to base acceptance on this test.

Resilience

Silicone has excellent resilience when cured. However, the thickness required to run a resilience test similar to the one run on other sealants requires very long periods to cure completely.

Weatherometer Tests

A specimen has been weathered for 5300 hours which is the equivalent of 16 years service with no obvious adverse effects. Silicone compound are relatively inert.

Ozone Resistance

This is a possible accelerated weathering test that may eliminate some materials.

Adhesion-in Peel

This test method in accordance with Federal Specification TT-S-00230 appears to offer a method by which the material could be accepted. The method involves the application of a 1/8 inch (approximately 3.18 mm.) layer of the sealant to a substrate, concrete surface; coating it with a cloth impregnated with sealant, rolling to 1/16 inch (1.59 mm.) thickness, curing for seven days and measuring the force required to peel the cloth when folded back 180 degrees. The force required to peel one inch strips is measured and percent of adhesion failed area is determined. This is a realistic test for the following reasons:

1. It can be used to evaluate the adhesion on a surface similar to the one it is required to adhere to in actual service.
2. A comparison of adhesive strength and cohesive strength is made.
3. The thickness required is not so great that long periods of cure are required.
4. The results promise to be more repeatable than most other tests and unlike most other bond tests for sealants the material can be tested to failure and a numerical value is obtained which would enable correlation with other parameters to be attempted.
5. Because of the low strength and high elongation properties of low modulus silicone fabric reinforcement facilitates testing.

The adhesion in peel test in conjunction with some very general requirements from other tests may be used as a basis on which to accept silicone sealants.

Field Installation

On November 6, 1974 Dow Corning 790 Building Sealant was installed in ten joints on Interstate 75 the sealant section was approximately 5/16 wide x 1/4 inch deep (7.94 mm. x 6.35 mm.). On March 4, 1975 an installation was made in five joints in a faulted section of I-85. The sealant section was approximately 3/8 wide x 3/8 inch deep (9.52 mm. x 9.52 mm.). Also, approximately 60 feet (18.3 meters) of shoulder joint between the concrete slab and asphaltic concrete shoulder was sealed. All of these joints are effectively sealed as of July 1976 and there is no reason to expect failure in the immediate future.

Installation Equipment

Caulking guns are available with which the material can be installed. Because if is one component and of uniform consistency regardless of temperature installation equipment should not be a problem. Hand operated guns are undesirable and a pneumatic gun should be used when large scale highway installations are made. Also, consideration should be given to the installation of the Dow ethafoam back up material which must be maintained to the proper depth to achieve the desired shape factor. A gun filler is available which will fill caulking guns with almost no material waste. This filler can be left in the container of bulk material overnight and operation can be resumed the next day with no difficulty by removing only a film of cured material from the filling snout.

CLOSED CELLULAR NEOPRENE

Closed cellular neoprene comes in many forms. The form used for highway contraction joints is a strip of a somewhat chevron cross-section with a smooth outer skin. Because the cells are not interconnected, the weight increase after immersion in water at room temperature is practically nil. There are five ASTM firmness grades, ASTM D1056, although research should be done to determine which grades perform best as a rigid pavement contraction joints seal, good results have been obtained with material having a firmness of about 13 psi (91 kpa.) at 25% deflection or the middle of the firmness range. (ASTM D1056). Since the firmness is determined on specimen from special sheets of uniform thickness and only the finish product was available, this firmness is only approximate. The information was not available from the manufacturer.

To be acceptable as a joint sealant a material must be resistant to aging and weathering. Durability of solid neoprene is well known and well established but some doubt has been expressed concerning the ability of closed cellular neoprene to perform in the severe environment of a roadway. The test installation for I-20 has been in place for five years. A somewhat weathered surface has been apparent on some seals for several years,

but the damage seems to be only superficial and has not impaired the sealing ability. Some damage was done to many of the seals by the installation machine which broke the skin and permitted some penetration of solvent which was used in the installation process. Another limited installation on I-20 has been in place for about ten years. Although some seals have failed in cohesion in portions outside lanes were faulting is greatest, the material is still resilient, well bonded to the joint face and there is no evidence that weathering has impaired the ability of the seal.

Low solids lubricant-adhesive is very effective in obtaining a bond between the seal and the concrete when applied properly. The lubricant adhesive must be applied well ahead of the sealing and allowed to become tack free. The seal is then saturated with solvent which has the effect of reactivating the lubricant adhesive to the extent that lubricating quality is restored but bond to the concrete is sufficient to prevent it from being stripped from the joint by a squee-gee effect from the insertion of the sealing strip. Installation of the seal without the lubricating effect is difficult if not impossible. The closed cellular seal in-place for 10 years on I-20 is still well bonded to the joint faces. In most cases the bond to the concrete is stronger than the neoprene and a seal cannot be removed intact after the adhesive has cured.

Closed cellular neoprene strips have been available at less than one half the price of solid neoprene seals of similar size. This is explained by the fact that less raw material is needed for seals of comparable size and complicated precision dies needed to produce the intricate webs members typical of most solid neoprene seals are not required.

Installation

The procedure used to install closed cellular neoprene is different from that of open cell seals. It is doubtful that equipment used to install open cell seals could be adapted to install closed cell seals. As with all preformed seals the seal must be installed without stretch but the principle employed to prevent stretch differs from that of the open cell neoprene installers. The machine used on I-20 had a disc similar to a bicycle sprocket which ran on the top of the seal and forced it into the joint (Figures 7 and 8). The teeth on the sprocket imbedded into the seal enough to prevent it from stretching when it was inserted. The machine used was the property of Middlestadt Corporation and they have not been commercially available. However, a sealant contractor has acquired the machine to install closed cell seals on a contract that allows the use of either closed cell or neoprene. We should soon know if closed cell seals can be specified, produced, and practically installed on a contract basis.

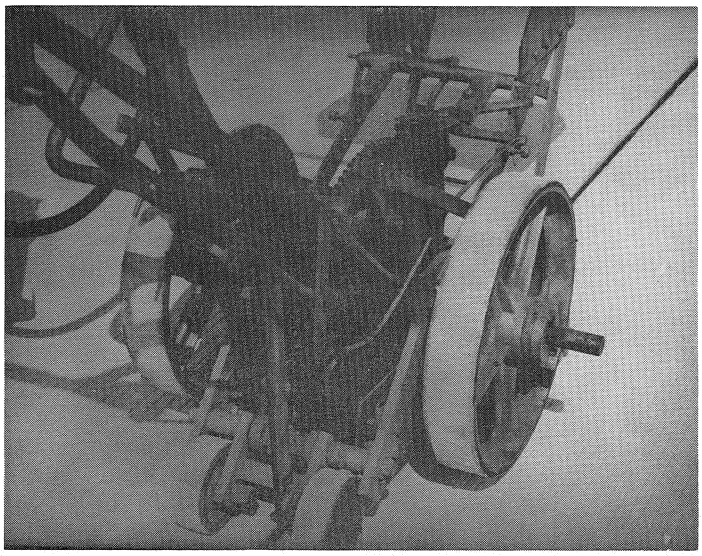


Figure 7
Installation machine for closed cell neoprene. Sprocket runs on top of seal, inserts seal while restricting stretch.

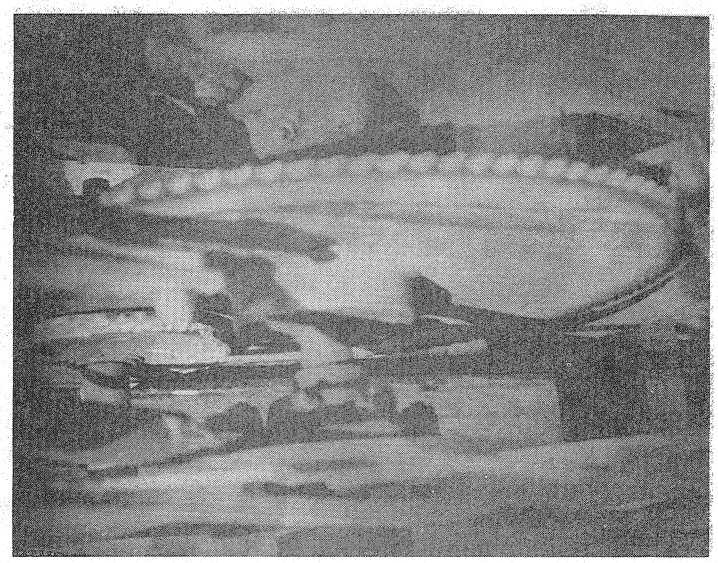


Figure 8
Close up of sprocket top view on machine in Figure 7.

Specifications

Properties of closed cell neoprene extrusions vary greatly. Closed cell neoprene is available in firmness grades ranging from soft to very firm and densities may range from 10 to 50 pounds per cubic foot (160 to 801 kgs. per cubic meter).

Material of different densities may perform as a sealant, but experience in Georgia is with material approximately 25 pounds per cibic foot (400 kgs. per cubic meter). The cross section of the seal was a chevron shape about 3/4 inch (19.1 mm.) wide 5/8 inch (15.9 mm.) deep with a 3/8 inch (9.5 mm.) bond surface when un-compressed. Figure 9 shows the seal prior to insertion and after installation.

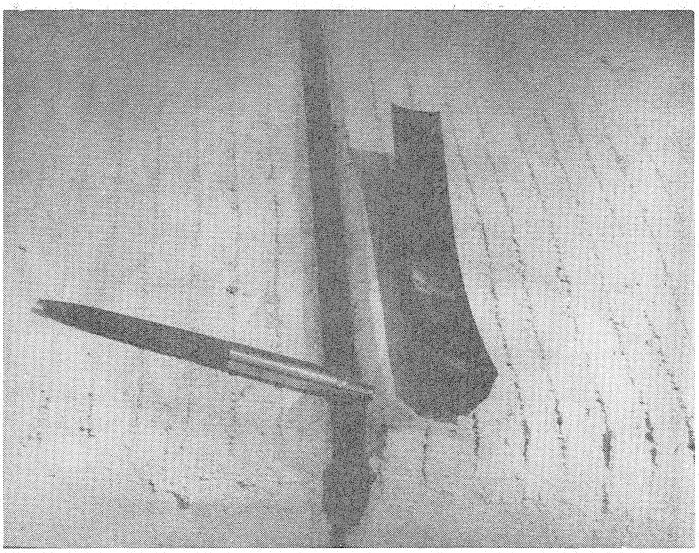


Figure 9
Preformed closed cell neoprene before and after installation.

It is important that the installation procedure be such that the maximum effect of the lubricant-adhesive is obtained. This must be specified. Apply lubricant-adhesive well ahead of the sealing and using a suitable solvent to reactivate the surface and make it slick, but not enough to remove the adhesive from the joint face. The result is that a

film of adhesive remains between the seal and the joint face and wets both surfaces. In this manner a good bond is achieved. A test procedure which approximates this procedure has been proposed.

The test required that the bond be sufficient to extend the approximately 3/4 inch (19.1 mm.) wide seal to one inch before bond failure occurs.

Movement Capability

Georgia's specifications require that contraction joint seals accommodate 1/4 inch (6.35 mm.) movement. For closed cellular compression seals this is defined as the difference in the width of the seal under a load of 4 pounds per linear inch (714 gm. per cm. approximately) and 50 percent of the original width. For a 3/4 inch (19.1 mm.) seal this means that compression-deflection, 25% deflection, ASTM D1056 will have to be about 13 psi (91 kPa.). Since firmer material is very difficult to install a maximum force value at 50% deflection should be set. A realistic value appears to be 20-25 pounds per inch (3.6 kgs. per cm. to 4.5 kgs. per cm.) at 50 percent deflection. Since more raw material is required manufacturers will probably try to stay close to the minimum firmness allowable. Some difficulty exists because quality control samples are run on special samples and highway agencies can only test the finished product.

Joint Sealer Recovery Under 50% Deflection

Recovery shall be 85 percent after compression to half original thickness for 22 hours at 158°F followed by removal of compression for 48 hours. Recovery after 22 hours at 0°F shall be 85 percent. Since at high temperatures the material is compressed in service the hot recovery test approximates actual performance. The cold recovery is indicative of the compounding of the material. Perhaps the 85% hot recovery should be relaxed somewhat since it is difficult to meet. However, material can be produced that will meet.

Water Absorption

Water absorption is an indication of whether the material is closed cell or open cell. Closed cell material will not appreciably change its weight when immersed in water. A 5 percent increase appears to be realistic when the complete 5 inch (12.7 cm.) strip including cut ends is immersed.

Ozone Resistance

Neoprene is more ozone resistant than other elastomers.

Summary

Since experience has indicated that closed cellular seals are equal or superior in performance to open cell seals, Georgia's specifications permit their use. Although the seals are more difficult to install and more development needs to be done on installation equipment, the cheaper prices of closed cell seals may encourage their use. Attempts are being made to seal some projects with closed cell seals and they will be watched closely. Research should be done to determine which firmness grades are practical to use as joint sealants.

SUMMARY

Experience tends to indicate that sealing of transverse joints alone is not sufficient to eliminate problems caused by water infiltration. Attempts to seal shoulder joints have been mainly to periodically place some asphaltic material in the joint or to simply ignore the shoulder joint. It is now apparent that more attention must be given the shoulder joint if pavement performance is to be increased by maintaining a pavement system sealed from the infiltration of surface water. Preformed seals cannot be used in the shoulder joint unless concrete shoulders are used and other sealants have been relatively ineffective. Low modulus silicone sealant may be an effective sealant for the joint between the concrete pavement and asphalt shoulder.

Although closed cellular neoprene is harder to install than open cell the cheaper material cost may make it competitive. The performance is superior. Low modulus silicone sealant requires hand tooling but it may also be a good alternate to preformed seals.

Care must be taken to see that all are properly installed. Silicone has the advantage that it can also be used in the shoulder joint and that it does not require a perfect saw cut to effect a watertight seal.

Future development of sealants for concrete pavements should center around the following:

1. Open cell seals with high solids adhesives or modification of installation to obtain optimum effect of the low solids adhesive.
2. Closed cellular neoprene seals.
3. Low modulus silicone seals.

Consideration is being given to allowing the 3 choices on an equal basis in Georgia.

REFERENCES

[1] Blanchard, Arthur H., "American Highway Engineers Handbook", John Wiley and Sons, Inc., First Edition 1919.

[2] Cook, John P., "Construction Sealants and Adhesives", Wiley-Interscience A Division of John Wiley and Sons, Inc., Copyright 1970.