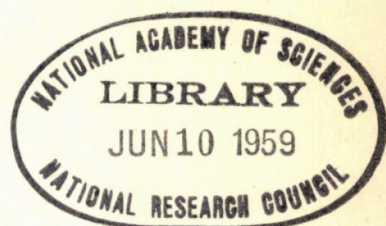NRC. **HIGHWAY RESEARCH BOARD**

Bulletin 211

Sealers for Joints and Cracks in Concrete Pavements

National Academy of Sciences—

National Research Council
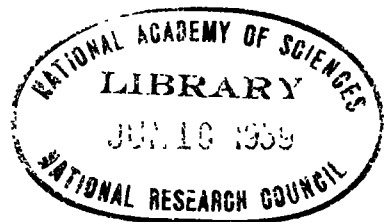
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Sealers for Joints and Cracks in Concrete Pavements

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Contents

Laboratory Tests of Sealers for Sawed Joints

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      The performance of sealing materials for sawed joints is being studied by a laboratory test in which the joints are opened and closed at speeds of the order of $\frac{1}{32}$ in. per hr. The sealers are applied to sawed joints which are initially $\frac{1}{8}$ or $\frac{3}{16}$ in. wide and which are usually opened an additional $\frac{1}{8}$ in. at 0 F during the tests. This test procedure appears to be more severe than method 223.11 of Federal Specification SS-R-406C. Tests have been conducted on conventional sealers as well as on materials which are still in the development stage or which have been developed for other applications.

      The results have shown that extensibility is not strictly an inherent property of the material, but is highly dependent on the relative dimensions of the cross-section of the sealer, referred to as the "shape factor." The importance of the shape factor indicates the desirability of developing suitable elastomers in shapes or forms that would avoid the high stress concentrations which cause bond failures. Foams or hollow shapes might satisfy these requirements. The conclusion is drawn that initial joint widths must be designed in relation to the joint sealer material, the joint spacing, and the climate.

      Although material costs of some potentially useful sealers are high, they may not be high in terms of lifetime performance.

      The work reported covers the period 1955 through 1957 and is part of a continuing program.

● IN 1955 a program of tests was started at the Portland Cement Association laboratories directed toward finding a sealer that would be more satisfactory for use in sawed joints than those now commercially available.

Discussions at that time with a number of manufacturers of plastics and rubbers who supplied materials which they considered to have potential value as joint sealers placed no maximum limitation on cost. Since then, approximately 70 samples have been received, representing about a dozen different types of material. Some of these were found almost immediately to be unsuitable. Others were found to be of considerable interest, even though costs of some are higher than those of presently used sealers.

The initial inquiries to manufacturers requested materials which would be capable of undergoing deformations of at least 100 percent in $\frac{1}{8}$-in. wide joints at a temperature of 0 F. Materials were received from a number of manufacturers who expressed confidence that their products were not only reasonably insensitive to temperature but would undergo "elongations" of 300 or 350 percent, far in excess of the stated requirements. When tested on the machine shown in Figure 1, however, either at 73 F or 0 F, some of these materials failed from increases in joint width of only 50 to 80 percent, values which are at great variance with the performance predicted on the basis of other test methods. This difference is due, at least in part, to a testing factor which in the compression-testing of elastomers has become known as the shape factor. The same term is used here, even though concern is with tension rather than compression.

SHAPE FACTOR

Figure 3 represents one concept of the effect of the shape factor on the tensile strain of elastic materials. If a rubber shape such as A-1 is to be stretched 100 percent longitudinally, the point P_1 will then appear at the position P_2 in B. To get to this point

it has moved through the resultant of the vertical distance a_1 and the horizontal distance b_1. If these two distances were magnified six times and the resultant plotted, it would be as shown in the small rectangle. However, if this same piece of material is tipped up on end, as at A-2, and a new point, P_3, is chosen on a top edge, stretching this material in a direction parallel to the shortest dimension of the piece moves P_3 to the point P_4. It has traveled through the resultant of the vertical distance a_2 and the horizontal distance b_2. If these distances also are magnified six times and plotted, the new resultant shown in the lower rectangle is obtained. This resultant is tremendously large compared to the resultant in B. In both cases the material has been stretched 100 percent, but in the second case the stress concentrations at P_4 and at any point on the surface are very great.

From this illustration, it is obvious that in pavement joints the materials are

Figure 1. Machine for testing joint sealers.

Figure 2. Gun for sealing joints.

being stretched in the least favorable direction. Extensibility of elastomers and other materials, determined by stressing them longitudinally, may be referred to as "elongation." To avoid confusion with this type of measurement, the term "deformation" has been used herein when referring to the stretching of sealers in concrete joints.

MATERIALS AND EQUIPMENT

Testing Equipment

Figure 1 shows a testing machine built in the PCA laboratory for testing sealers for sawed joints. By means of a 28,736-to-1 speed reducer, a 32-thread-per-inch screw, and an appropriate pulley combination, the speed of a 1750-rpm motor is translated into a speed of approximately $\frac{1}{32}$-in.-per-hr travel in the movable bed. One end of each of three $2\frac{1}{2}$- by 4- by 16-in. concrete blocks is clamped to a fixed bed, and other end being clamped to the movable bed. The blocks contain sawed joints, which were in most cases $\frac{1}{8}$ in. wide and 2 in. deep. Micrometer heads mounted in the arm on the side of the carriage, which come to bear against the two limit switches in the foreground, control the ultimate distance of travel in either direction. The machine, mounted on casters for ease of transfer, may be operated either in laboratory air at 73 F or in a walk-in freezer at 0 F. The speed of $\frac{1}{32}$ in. per hour was chosen because it represents a travel rate per hour of 25 percent of the initial joint width, which is comparable to that used in the standard ASTM and Federal specification bond tests for joint sealers. The speed can, however, be modified by changing the pulley combinations.

Preparation of Specimens

Concrete blocks, $2\frac{1}{2}$- by 4- by 16-in. (Fig. 4) were made of a 6-sack mix using an aggregate of $\frac{3}{4}$-in. maximum size. The concrete, with a slump of 2 to 4 in. and an air content of 3.5 to 7 percent, was placed in the molds with vibration. The blocks were cured 7 days in the moist room, then stored at 73 F and 50 percent relative humidity. Flexural strengths of 29 batches of concrete at 7 and 28 days were in the ranges 480 to 610 psi and 520 to 880 psi, respectively, and compressive strengths were in the ranges 3,250 to 4,460 psi and 5,000 to 6,520 psi, respectively.

The concrete blocks were lightly reinforced with $\frac{1}{4}$-in. steel wires in each end but not crossing the joint. The blocks were made in wood molds containing metal inserts of the shape shown in Figure 4. The finished blocks contained tapered openings in the
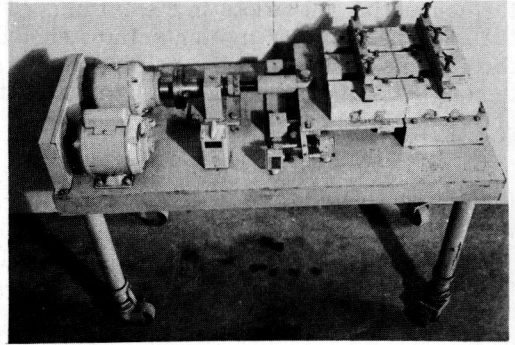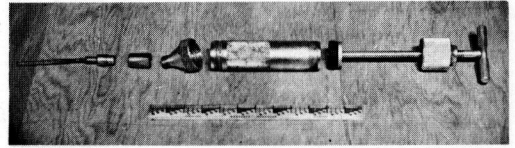
top connecting with slots in the bottom. The slots were fitted over cross-bars of the testing machine, and molten sulfur, such as used for capping cylinders, was poured through the openings in the top to obtain a snug fit to the cross-bars. The blocks were then held down against the bed by means of the leather-faced steel bars in the assembly shown in Figure 1.

The joint at the center of the block was sawed with a diamond saw when the specimen was stripped from the mold at age one day. The saw produced a slot about $\frac{1}{10}$ in. wide. Before sealing, the block was broken by hand in flexure below the saw cut. The joint was then opened to the desired width, such as $\frac{1}{8}$ in., and clamped in a jig for sealing.

The sawed surfaces of blocks to be sealed with asphaltic- and coal-tar-base materials were wire-brushed before assembling in the jig, in accordance with a common recommended practice for field applications. Before sealing, all joints were cleaned by blowing with compressed air. Unless the sealer was of unusually low viscosity it was applied to the joint by a caulking gun with a narrow nozzle (Fig. 2) and the joint was sealed from the bottom up. When the joint was to be sealed only to a shallow depth, a thin slab of styrofoam or bar of aluminum was fitted in the bottom of the joint, using a ribbon of wax paper on the top edge, if necessary, to prevent bond. The aluminum bar was removed before testing. Primers, supplied with some sealers (notably silicone
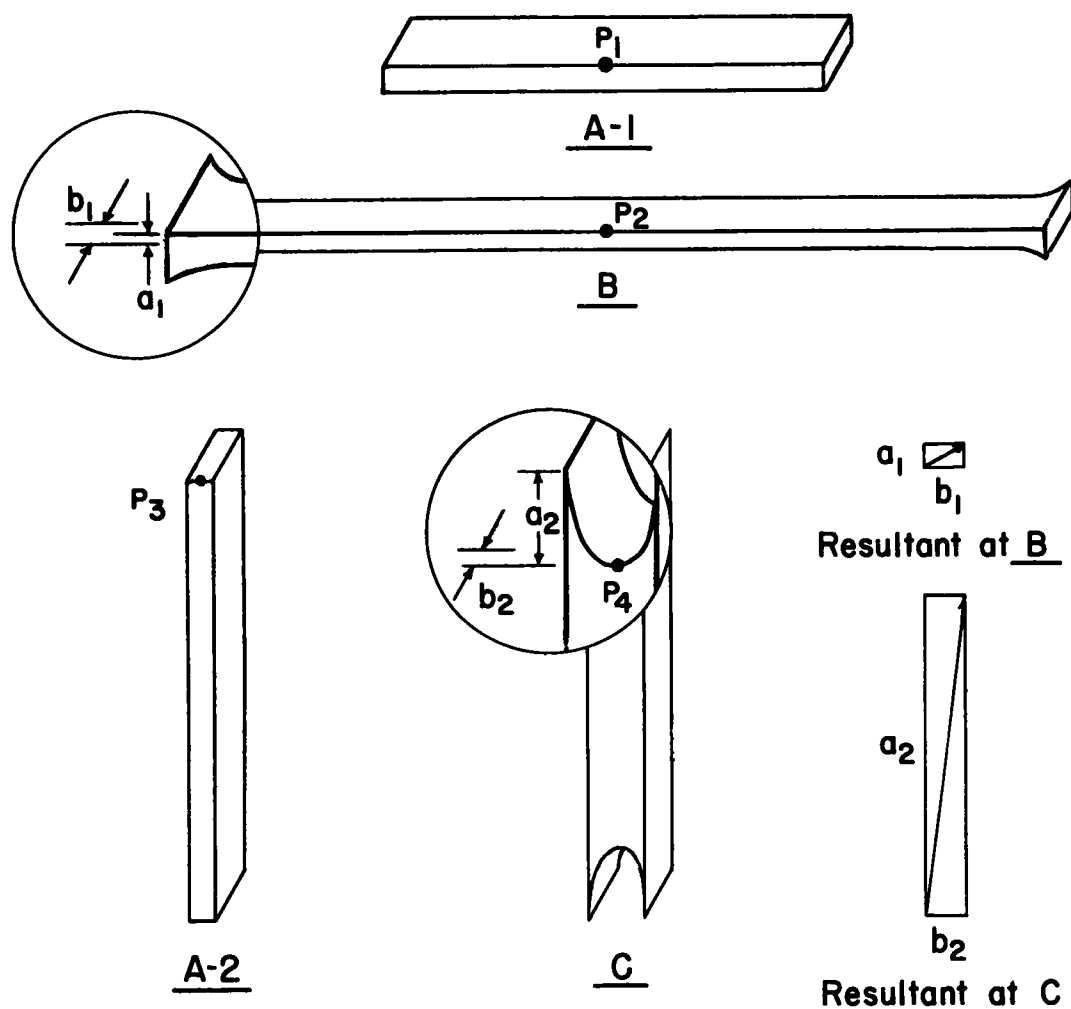

Figure 3. Shape factor: effect of shape on tensile strain of elastic materials.

rubbers and some polysulfide rubbers), were applied according to the manufacturers' directions. The sealed joint was left in the jig until the specimen was transferred to the testing machine. Those sealers which required a curing period were kept in the jig long enough for ample curing.

TEST PROGRAM

The tests have included both commercial and experimental sealers. Many commercial sealers conformed to one of the following Federal Specifications:
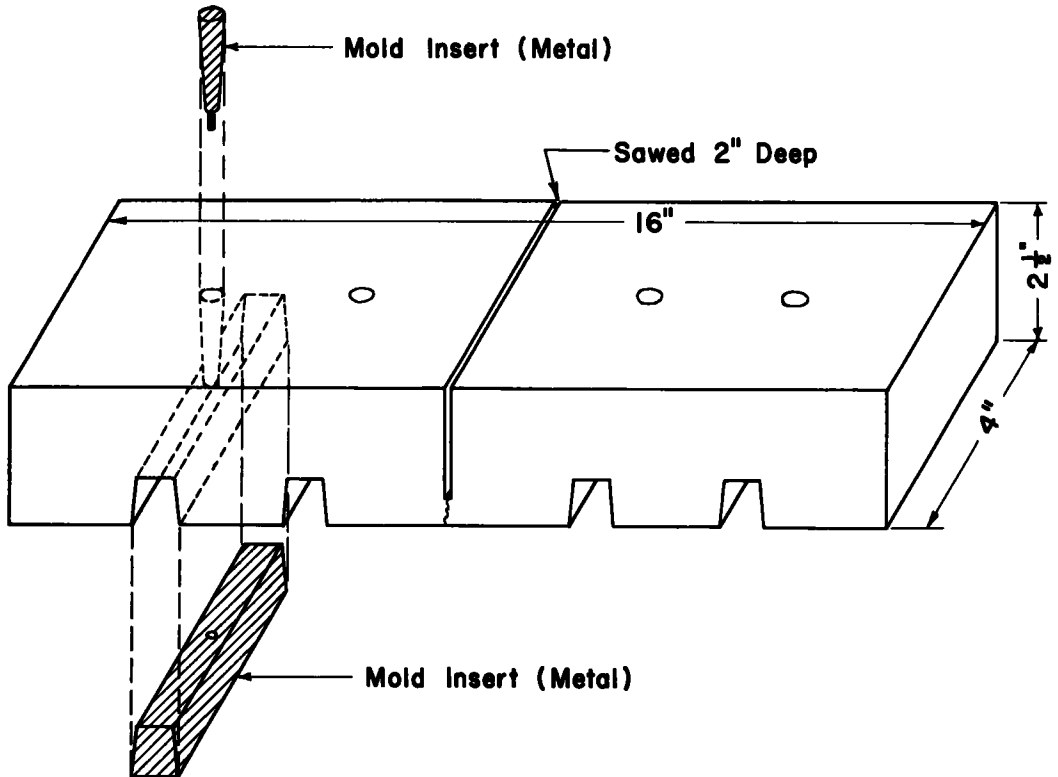
Figure 4. Concrete block with mold inserts.

TABLE 1

TYPES OF SEALERS TESTED IN VARIOUS SERIES

Material	Specification	Series	Table
Asphalt		B	4
Asphalt, asbestos-filled		A,B	3,4
Asphalt, mineral-filled	Texas, Arkansas	B	4
Asphalt, rubber	Miscellaneous state	B	4
Asphalt, rubber	None	A,B	3,4
Asphalt, rubber	SS-F-336a	B,G	4,8
Asphalt, rubber	SS-S-159	B	4
Asphalt, rubber	SS-S-164	A,B	3,4
Asphalt, rubber	SS-S-167	A,B	3,4
Asphalt, rubber	SS-S-170	A,B,E	3,4,6
Cellular rubber		C	See Text, p. 17
Epoxy, modified		B	4
Epoxy-amide		B	4
Neoprene putty		B,D	4,5
Polyester		B	4
Polysulfide rubber		A,B,D,G	3,4,5,8
Polyurethane		B	4
Polyurethane foam		A	3
Silicone rubber		A,B,D,E	3,4,5,6

SS-S-159   A mastic-type sealer.   May have either
           one or two components.

SS-F-336a A hot-applied, one-component sealer.
           This specification has been replaced by
           SS-S-164.

SS-S-164   A hot-applied, one-component sealer.
           This specification replaces SS-F-336a.

SS-S-171   Mineral-filled sealer containing dia-
           tomaceous earth.

SS-S-167   Hot-applied, one-component jet-fuel-
           resistant (JFR) sealer.

SS-S-170   Cold-applied, two-component, JFR sealer.

An index of the test materials is provided in Table 1.   A summary and comparison of the test procedures used in the various series, together with a statement of their purposes, is given in Table 2.

Because of the limited capacity of the testing machine and the time required for a single cycle, only one specimen per sealer was used for most tests.   Although this procedure might be considered unfair to sealers which happened to fail early, the test results establish definite trends and indicate which classes of sealers are most worthy of further study.

Cycling Tests

In exploratory tests (Series A, Table 3) in which a number of sealed joints were opened by 100 percent at 0 F, only one specimen survived one complete cycle.   A series of tests (Series B) was then initiated in which sealed joints were opened and closed at 73 F in cycles successively increasing in magnitude of opening by 20 percent increments. In the test procedure for Series B (Table 4), the cycles sometimes ranged from 60 to 100 percent increase in joint opening, and sometimes from 60 to 160 percent increase. Some sealers which survived these tests at 73 F then were subjected to additional cycling at 0 F.

Of two rubber-asphalts tested through the 160 percent cycle, one survived the last cycle intact.   This was a two-component JFR sealer (J37).   The other, a mastic sealer (J47), failed during the 160 percent cycle.   These contrast with one other two-component JFR sealer (J43) and two other mastic sealers (J38 and J42) which failed in early cycles at 73 F (Table 4).

Seven other commercial sealers tested only through the 60, 80, and 100 percent cycles at 73 F, were subjected to cycling at 0 F.   Of these, one (J59, a hot-poured JFR

TABLE 2
COMPARISON OF TEST PROCEDURES IN VARIOUS SERIES

Series	Increase in Opening During Successive Cycles[1] at 73 F (% of init. width)	Increase in Opening During Cycles[1] at 0 F (% of init. width)	Testing Speed (in. per hr)	Initial Joint Width (in.)	Initial Joint Depth (in.)	No. of Specimens per Sealer	Purpose of Series
A		100	$\frac{1}{32}$	0.125	2	1 to 3	Exploratory
B	60, 80, 100, (120, 140, 160)[2]	100[3]	$\frac{1}{32}$	0.125	2[4]	1	Elimination of sealers
C	40, 60, 80, 100, 120, 140	-	$\frac{1}{32}$	0.264-0.386	2	4	Evaluation of preform foam as sealer
D	-	100	$\frac{1}{32}$	0.125	$\frac{3}{8}$ or 2	3	Evaluation of sealers
E	-	67	$\frac{1}{32}$	0.188	$\frac{3}{8}$ or 2	3	Evaluation of sealers
G	-[5]	-[5]	$\frac{1}{8}$	Varies	$\frac{1}{2}$ or 2	12	Shape factor study

[1] One cycle consists of:
  1. Conditioning the sealed joint at least 2 hr at the temperature to be used in stretching, if not already at that temperature.
  2. Opening the joint the indicated amount at a rate of $\frac{1}{32}$ in. per hr at 73 F or 0 F (see Col. 2 and 3).
  3. Holding the joint in the stretched condition overnight at the stretching temperature.
  4. Conditioning the joint at least 2 hr at 73 F if not already at 73 F.
  5. Closing at $\frac{1}{32}$ in. per hr at 73 F until the joints were open only 10 percent beyond their initial width.
[2] Cycles in parentheses omitted in some tests.
[3] Following indicated series of cycles at 73 F.
[4] Except as noted for J22 and J44 in Table 4.
[5] Specimens not cycled, but stretched continuously to failure at a rate of $\frac{1}{8}$ in. per hr.

rubber-asphalt) failed in the fifth 0 F cycle, one (J57, a hot-poured rubber-asphalt) in the fourth, and one (J58, a solvent-system rubber-asphalt) in the second. One other hot-poured rubber-asphalt (J36) had not failed in adhesion or cohesion by the end of the first 0 F cycle, but it had become badly deformed in the first and second 73 F cycles. An asphalt (J26), a mineral-filled asphalt (J39), and a rubber-asphalt (J6) failed in the first 0 F cycle. The performance of commercial sealers as a group was quite variable, but it is likely that if more specimens of each sample had been tested the performance would have been variable for any one sealer. (Note, for example, the differences between sealer J43 in Table 4 and the same sealer in Table 6.)

Two samples of Neoprene putties survived cycling at 73 F through the 160 percent cycle, and two others through the 140 percent cycle. One Neoprene putty (J33), which had been through the 160 percent cycle, did not fail during a subsequent cycle at 0 F, after which it was taken off test. These sealers, as well as the rubber-asphalts, are subject to some permanent, irregular deformation of the exposed surfaces.

A polyester caulk (J20) also survived cycling at room temperature through the 160 percent cycle, then failed in the first cycle at 0 F.

One silicone rubber (J18-3) failed in the 100 percent cycle at 73 F. This failure occurred on standing overnight in the stretched condition.

A black polysulfide rubber (J22) failed in the 80 percent cycle at 73 F. A new sample (J44) of gray polysulfide rubber with approximately similar properties and obtained from the same manufacturer, was used in preparing three specimens in which the joints were not sealed to the full depth. One was sealed to a depth of $\frac{1}{4}$ in. and one to a depth of $\frac{1}{2}$ in. A third was sealed along the top of the saw cut to a depth of $\frac{1}{4}$ in. and along each end to a horizontal distance of $\frac{3}{8}$ in. These three specimens failed in either the 140 or 160 percent cycles, showing that this sealer can be deformed farther before failure if it is placed in the joint to shallow depths, a result which should be expected from the effect of the shape factor.

The epoxy amide sealers, modified epoxy sealer, and urethane sealers failed in the first cycle. The suppliers of these experimental sealers are investigating new formulations of these materials.

TABLE 3

SERIES A TESTS OF JOINT SEALERS[1,2]

Type of Material	Laboratory Sample No.	Number of Specimens	Spec. or other Description	Type of Failure
Asphalt, asbestos-filled	J24	1		Adhesion
	J6	1	SS-S-164	Adhesion
	J37[3]	2	SS-S-170	Cohesion, adhesion
Asphalt, rubber	J37	1	SS-S-170	Adhesion
	J61	1	Solvent system	Adhesion
	J61A[4]	1	Solvent system	Adhesion
	J1	1	Black, two component cold-applied[6]	Tension in concrete[5]
Polysulfide rubber	J2	1	Black, two component, cold-applied[6]	Cohesion
	J22	1	Gray, two component, cold-applied[7]	Adhesion
Polyurethane foam	J21	1	Foamed-in-place rubber	Cohesion[8]
	J17	1	Red, two component, cold-applied[6]	Adhesion
Silicone rubber	J18	5	White, two component, cold-applied[6]	Adhesion[8,9]

[1] All joints initially $\frac{1}{8}$-in. wide, sealed to full depth of 2 in. Test Procedure:
    1. Sealed joint opened to 100 percent increase in initial width at rate of $\frac{1}{32}$ in. per hr at 0 F.
    2. Joint held in stretched condition overnight at 0 F.
    3. Joint conditioned 2 hr at 73 F.
    4. Joint closed at 73 F at same rate of speed to 10 percent increase in initial width.
[2] All specimens except one failed in first cycle.
[3] Sealed by manufacturer.
[4] Adhesive asphalt applied to concrete before sealing.
[5] High modulus sealer, did not fail; concrete failed in tension.
[6] Primer furnished.
[7] No primer furnished.
[8] Failed during thawing.
[9] One specimen did not fail.

TABLE 4
SERIES B TESTS[1],[2] OF JOINT SEALERS

Type of Material	Laboratory Sample No.	Specification or other Description	At 73 F 60%	80%	100%	120%	140%	160%	At 0 F 100%	100%	100%	100%	100%	Type of Failure
Asphalt	J26		x[3]	x	x	-	-	-	F					Cohesion
Asphalt, modified	J46	Experimental	F[3]											Cohesion
Asphalt, mineral-filled	J39	Ark., Tex. specs.	x	x	x	-	-	-	F					Adhesion, cohesion
Asphalt, asbestos-filled	J23		F											Adhesion
	J24		x[4]	-	F									Adhesion
	J40		x[5]	-	F									Adhesion
	J51		F											Cohesion
	J52		F											Cohesion
Asphalt, rubber	J38	SS-S-159	x[5]	x	F									Cohesion
	J42	SS-S-159	F[6]											Flowed badly
	J47	SS-S-159	x	x[4]	x	x	x	F						Cohesion
	J57	SS-F-336a	x	x	x	-	-	-	x	x	x	F		Cohesion
	J60	SS-F-336a	x	F										Adhesion
	J6	SS-S-164	x	x	x	-	-	-	F					Adhesion
	J35	SS-S-164	x	x	F									Adhesion
	J64	SS-S-164	x[5]	x	x	F								Unknown
	J59	SS-S-167	x[3]	x	x	-	-	-	x	x	x	x	F	Cohesion[7]
	J63	SS-S-167	F											Adhesion
	J37	SS-S-170	x	x	x[5]	x	x	x	-	-	-	-	-	None
Coal tar, rubber	J43	SS-S-170	F											Adhesion
Asphalt, rubber	J36	Michigan spec.	x[4]	x[5]	x	-	-	-	x					None
	J58	Various state specs.	x	x	x	-	-	-	x	F				Cohesion
Epoxy amide	J27	Two-component elastomer	F											Adhesion, cohesion
	J45	Two-component elastomer	F											Adhesion[8]
Epoxy, modified	J53	Two-component, hot-applied	F											Adhesion
Neoprene putty	J33	Two-component elastomer	x	x	x	x	x[4]	x	x					None
	J34[9]	Two-component elastomer	x	F										Adhesion
	J41	Two-component elastomer	x	x	x	x	x	F						Adhesion
	J41-2[7]	Two-component elastomer	x	x	x	x	x	F						Adhesion
	JC41	Two-component elastomer	x	x	x	x	x	x	F					Adhesion
Polyester	J20	Two-component caulk	x	x	x	x	x	x	F					Cohesion
Polysulfide rubber	J22	Two-component elastomer	x	F										Adhesion
	J44-1[11]	Two-component[10] elastomer	x	x	x	x	x	F						Cohesion
	J44-2[12]	Two-component[10] elastomer	x	x	x	x	x	F						Cohesion
	J44-3[13]	Two-component[10] elastomer	x	x	x	x	F							Cohesion
Silicone rubber	J18-3	Two-component elastomer	x	x	F									Cohesion
Urethane	J28	Air-curing caulk	F											Tension in concrete[14]
	J29	Air-curing caulk	F											Tension in concrete[14]
	J30	Air-curing caulk	F											Tension in concrete[14]
	J31	Air-curing caulk	F											Tension in concrete[14]
	J32	Air-curing caulk	F											Adhesion[8]
	J48	Air-curing caulk	F											Adhesion[8]
	J49	Air-curing caulk	F											Adhesion[8]
	J50	Air-curing caulk	F											Adhesion[8]

[1] All joints initially ¼ in. wide, sealed to full depth of 2 in.

[2] Test Procedure:
Cycle 1. (a) Sealed joint opened to 60 percent increase in initial joint width at rate of 1/32 in. per hr at 73F.
(b) Joint held in stretched condition overnight.
(c) Joint closed at same rate to 10 percent increase in initial width.
Cycle 2. Repeat 1b at open to 80 percent.
Cycle 3 Repeat 1b at open to 100 percent.
Cycle 4. Repeat 1b at open to 120 percent
Cycle 5. Repeat 1b at open to 140 percent.
Cycle 6. Repeat 1b at open to 160 percent.
(Note: Cycles 4, 5, and 6 sometimes omitted.)
All succeeding cycles (a) Condition sealed joint at least 2 hr at 0 F then open to 100 percent increase in initial joint width at rate of 1/32 in. per hr.
(b) Repeat 1(b) at 0 F.
(c) Condition joint at 73 F for at least 2 hr.
(d) Repeat 1(c).

[3] Sealer has partially flowed out of specimen.

[4] Top surface contains depressions varying by more than 3/8 in from the general surface

[5] Top surface uniformly depressed 3/8 in. or more at center of joint

[6] Top surface contains depressions varying by more than ¼ in from the general surface

[7] Failure may be result of air void

[8] High modulus sealer produced distortion of test machine and little or no joint movement prior to failure

[9] Same as J33, but concrete surface primed

[10] No primer supplied or used with this polysulfide rubber

[11] Depth of fill = 0 250 in

[12] Depth of fill = 0 500 in

[13] Depth of fill = 0.250 in. except that joint was filled to full depth for a distance of 7/8 in from each end of joint

[14] High modulus sealer produced distortion of test machine and caused tensile failure of concrete while sealer remained intact

In Series D (Table 5), four sealers were tested in triplicate, cycling through 100 percent joint openings at 0 F. Neoprene putty was placed in the joints of three specimens to the full depth of 2 in., because it retains some plasticity after it has cured. These specimens failed in adhesion in the first cycle. A silicone rubber (J18-5) and two polysulfide rubbers (J56 and J62) were placed in the joints to depths of only 3/8 in. The silicone rubber failed in adhesion in the first cycle, and one polysulfide rubber (J62) failed in cohesion in the first and second cycles. The other polysulfide rubber (J56) failed in cohesion in the ninth and tenth cycles.

Series E (Table 6) was undertaken to determine whether a joint which was originally 3/16-in. instead of 1/8-in. wide could be repeatedly opened 1/8 in. without failure. Three specimens of silicone rubber sealed to a depth of only 3/8 in. failed in adhesion in the first cycle. Three specimens of a rubber-coal tar sealed to the full depth had not failed after 16 cycles, although the surfaces had become very irregular.

Cycling tests were then suspended, pending remodeling of the test machine to accommodate more specimens.

Test of Premolded Cellular Rubber

It was thought that a cellular rubber sealer would diminish the effect of the shape factor, and this was tested in Series C by using a sealed-cell rubber.

A 3/8-in. thick sheet of sealed-cell rubber was cut into 2- by 4-in. pieces. The flat 2 x 4-in. surfaces were roughened by abrasion, and the pieces were then bonded to the sawed surfaces of the joints by means of an adhesive. Two such specimens (J54-1 and J54-2) were stretched simultaneously to failure in a single cycle at room temperature. Two others (J54-3 and J54-4) were tested together, compressed to less than one-half their initial joint widths before stretching, and then stretched to failure in a single cycle. The results of Series C are summarized as follows:

TABLE 5

SERIES D TESTS [1],[2] OF JOINT SEALERS

Sealer	Laboratory Sample No.	Depth of Sealer (in.)	Cycle During Which Failure Occurred	Type of Failure
Neoprene putty	J41	2	1	Adhesion
		2	1	Adhesion
		2	1	Adhesion
Polysulfide rubber[3]	J56	3/8	10	Cohesion
		3/8	9	Cohesion
		3/8	10	Cohesion
Polysulfide rubber	J62	3/8	1	Cohesion
		3/8	2	Cohesion
		7/8	1	Cohesion
Silicone Rubber	J18-5	3/8	1	Adhesion
		7/8	1	Adhesion
		5/8	1	Adhesion

[1] All joints initially 1/8-in. wide, sealed to depths of 3/8 in. or 2 in.
[2] Test procedure:
  1. Sealed joint opened to at least 100 percent increase in initial width at rate of 1/32 in. per hr at 0 F.
  2. Joint held in stretched condition overnight at 0 F.
  3. Joint conditioned at 73 F at least 2 hr.
  4. Joint closed at 73 F at same rate of speed to 10 percent increase in initial width.
[3] No primer supplied or used with this polysulfide rubber.

Specimen	Width (in.)			Width (in.)		Recalculated Deformation, %
	Initial As Assembled	Increase at Failure	Deformation at failure, %	After Compressing	Increase at Failure from Compressed Width	
J54-1	0.379	0.377	100	-	-	-
J54-2	0.264	0.265	100	-	-	-
Average			100			
J54-3	0.386	0.523	135	0.185	0.724	391
J54-4	0.368	0.372	101	0.158	0.582	368
Average			118			380

The deformations at failure (Col. 4), based on the relaxed thickness of the rubber, are encouraging but are not as large as might be expected. If, however, the deformations at failure are recalculated on the basis of the width of the rubber when in compression, some extremely large deformations are observed, as shown in the last column.

TABLE 6

SERIES E TESTS [1],[2] OF JOINT SEALERS

Sealer	Specification	Laboratory Sample No.	Depth of Sealer (in.)	Cycle During Which Failure Occurred	Type of Failure
Silicone rubber	-	J18-5	$\frac{3}{8}$	1	Adhesion
	-	J18-5	$\frac{3}{8}$	1	Adhesion
	-	J18-5	$\frac{3}{8}$	1	Adhesion
Coal tar, rubber	SS-S-170	J43	2	>16	None[3]
		J43	2	>16	None[3]
		J43	2	>16	None[3]

[1] Joints initially $\frac{3}{16}$-in. wide, sealed to depths of $\frac{3}{8}$ in. or 2 in.
[2] Test Procedure:
    1. Sealed joint opened to 67 percent increase in initial width at rate of $\frac{1}{32}$ in. per hr at 0 F.
    2. Joint held in stretched condition overnight at 0 F.
    3. Joint conditioned 2 hr at 73 F.
    4. Joint closed at 73 F at same rate of speed to 10 percent increase in initial width.
[3] Sealer did not lose bond or fail in cohesion. However, the top and end surfaces deformed irregularly, and depressions of $\frac{1}{4}$ in. to as much as 1 in. in depth formed in the top surfaces. Test discontinued after 16 cycles.

Types of Failure

Failures between sealer and concrete have been referred to as adhesion failures, and those within the sealer itself as cohesion failures. When all failures in Tables 3, 4, 5, and 6 are summarized, it is found that 57 percent are adhesion failures, 36 percent cohesion failures, and 7 percent tension failures in the concrete. Of the failures of asphaltic and coal-tar sealers, 58 percent occurred in adhesion and 42 percent in cohesion. For the rubber-containing asphalts and coal tars the adhesion failures are increased slightly to 63 percent and the cohesion failures decreased to 37 percent. The ratio of adhesion to cohesion failures does not change greatly whether the failures occur at 73 F or 0 F.

It is interesting to note that of the other sealers tested in any quantity, all of the Neoprene putty sealers and 89 percent of the silicone rubber sealers failed in adhesion. The Neoprene putty is a semi-plastic sealer which undergoes a certain amount of cold flow. The silicone rubber is an elastomer of more limited deformability and higher tensile modulus. In contrast to these two sealers, 77 percent of the polysulfide subber sealers failed in cohesion, and only 15 percent in adhesion. (One polysulfide rubber sealer, or 8 percent, caused tensile failure of the concrete.) Hence, among these samples of elastomeric sealers, each type exhibited a highly preferred type of failure. Undoubtedly the "preference" would be changed by changes in physical properties. For example, an increase in tensile modulus might be accompanied by an increase in tensile strength and a shift from a cohesion failure to an adhesion failure.

In practice, cohesion failures might prove more tolerable than adhesion failures, provided fresh sealer can easily be bonded to old. This might be true of some of the elastomeric sealers. Obviously, failure by tension in the concrete must be avoided, and this requirement means that the sealer must have lower tensile strength
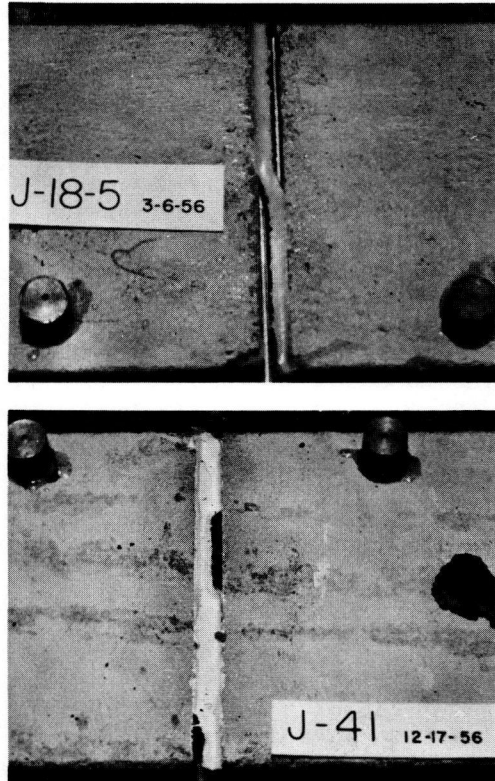

Figure 5. Adhesion failures of silicone rubber (J18-5) and Neoprene putty (J41).

than the concrete and a sufficiently low tensile modulus to allow the required movement.

Typical failures are shown in Figures 5, 6, 7 and 8. The condition of each of the time of photographing is given in Table 7. Adhesion failures of silicone rubber (J18-5) and Neoprene putty (J41) are shown in Figure 5. The silicone rubber in this picture was placed to a depth of $^3/_8$ in., and the light lines seen below the failure are the top edges of thin sheets of aluminum. In Figure 6 is seen the cohesion failure of a polysulfide rubber (J44-1). A sealer which failed both in adhesion and cohesion is shown in Figure 7. A high-modulus sealer which underwent a total deformation of only 2 percent and caused failure of the concrete is shown in Figure 8.

Relation of Deformation to Initial Width

It has been suggested that initial joint width should be dictated by the maximum change in joint opening expected and by the type of sealer used. A series of tests was planned to determine the relationship between deformability of sealer and initial joint width. Joints which were initially $^1/_8$, $^1/_4$, $^3/_8$, and $^1/_2$ in. wide were sealed to the full depth with a rubber-asphalt passing Federal Specification SS-F-336a. Three specimens were sealed for each initial width, making a total of twelve specimens. Another set of twelve specimens was sealed with a polysulfide rubber to the same widths, but to a depth of only $^1/_2$ in. The specimens were then tested to failure in a single cycle, opening the joint at a rate of $^1/_8$ in. per hr at 0 F. The increases in joint width at failure are recorded in Table 8 and plotted in Figure 9.

The valued for the rubber-asphalt sealer are not only much more erratic than those for the polysulfide rubber, but they also are considerably lower. It is believed that the irregular shape of the curve for rubber-asphalt may be the result of defective specimens. Further tests of this kind are planned to determine the position and shape of curves for a variety of materials. If the concept of the shape factor is correct, the lines for any elastomer placed in the joint to the full depth should curve slightly upward. However,

Figure 6. Cohesion failure of polysulfide rubber.

Figure 7. Failure of modified epoxy sealer in both adhesion and cohesion.

Figure 8. Failure of concrete resulting from high tensile bond strength and high tensile modulus of urethane sealer.

the lines for sealers placed in the joints to shallow depths may be essentially straight.

Curves of this kind should be established for all joint sealer materials for use in highway joint design. From such curves, appropriate choices could be made between

the related factors of initial joint width, type of sealer, and expected maximum joint opening. If any two of these factors were known, the third would be pre-determined. For example, if expected joint openings (which are primarily dependent on joint spacing and climate) and initial joint widths were known, the kind and quality of sealer would be dictated by the curves, allowing a suitable safety factor. If, on the other hand, a particular sealer were to be used for a given joint spacing in a particular climate, the initial joint width would be dictated.

COSTS OF SEALERS

The material costs of some of the sealers tested are of a different order of magnitude from those previously encountered—ranging above $20 per gallon for some sealers. It is likely, however, that some of these prices will be reduced substantially if the highway market creates a large demand.

Estimating the material cost of sealer, a rubber-asphalt would cost about $400 per mile compared to $1,500 to $2,000 per mile for a polysulfide rubber. The rubber-asphalt would be placed to a depth of 2 in. and the polysulfide rubber to a depth of only $\frac{1}{2}$ in. using some less expensive nonsealing filler below it. As previously shown, polysulfide rubber sealers are more successful when used in shallow depths than in full depths. Although the difference in cost is large when considered alone, it is not large when considered in the light of the magnitude of the investment in concrete pavement, for the protection of which an efficient sealing system is essential for improved performance, longer service life, and lowered maintenance expenses.

CONTINUATION OF PROGRAM

The program of testing is still in progress. Because of widespread interest in the development of a completely satisfactory system for sealing joints in highway pave-

TABLE 7

CONDITION OF FAILED SEALERS WHEN
PHOTOGRAPHED FOR FIGURES 5 to 8

Sealer	Series	Depth of Fill (in.)	Deformation When Pictured[1] (%)	History
(a) Adhesion Failures				
J18-5	D	$\frac{3}{8}$	100	1 cycle at 0 F[2]
J41	D	2	114	1 cycle at 0 F
(b) Cohesion Failure				
J44-1	C	$\frac{1}{4}$	100	6 cycles at 73 F, 1 cycle at 0 F
(c) Adhesion-Cohesion Failure				
J53	B	2	40	1 cycle at 73 F
(d) Concrete Failure				
J31	B	2	2[3]	1 cycle at 73 F

[1] Not necessarily deformation at time of failure.
[2] Date shown on picture should be 3-6-57.
[3] While still under tension, before failure and before photographing.

TABLE 8

RELATIONSHIP OF ULTIMATE DEFORMATION[1] TO INITIAL JOINT WIDTH FOR TWO SEALERS

Sealer	Specification	Laboratory Sample No.	Depth of Seal (in.)	Initial Width (in.)	Increase in Joint Width at Failure (in.)	
					Indiv.	Avg
Rubber-asphalt	SS-F-336a	J57	2	0.125	0.217	
					0.099	0.158
				0.250	0.194	
					0.230	
					0.230	0.218
				0.375	0.200	
					0.207	
					0.227	0.211
				0.500	0.610	
					0.200	
					0.216	0.342
Polysulfide rubber	-	J77	$\frac{1}{2}$	0.125	0.403	
					0.455	
					0.426	0.428
				0.250	0.565	
					0.624	
					0.791	0.660
				0.375	0.946	
					1.035	
					1.208	1.063
				0.500	1.374	
					1.395	
					1.300	1.356

[1] Joints were opened continuously to failure in a single cycle at 0 F.

ments, and particularly sawed joints, it seemed desirable to report progress through December 1957 in evaluating sealers. A further report will be made when sufficient information becomes available.

CONCLUSIONS

Some commercial sealers containing rubber, and now on the market, represent a considerable improvement in joint sealers. Nevertheless, it is desirable to develop systems for permanently sealing joints which are far superior to those in present use.

Some materials which showed relatively good performance under these severe test conditions, but which are not yet finally proven either in the laboratory or in the field, are polysulfide rubbers, Neoprene putty, and silicone rubbers. Other materials may be added to this list as the present program continues.

Some sealers are far more satisfactory when placed in the joint to a depth of $\frac{1}{2}$ in. than when placed to a depth of 2 in. For these sealers this should be the standard method of application. It is likely that some of these materials will ultimately

Figure 9. Relation of ultimate deformation of sealer to initial joint width (rate of opening, 1/8 in. per hr).

satisfy the practical requirements of sealing without being placed to the full depth. Thus, by requiring less of these expensive materials per joint, the highway designer actually obtains more effective sealing.

It may be that formed-in-place sealers or preformed cellular rubbers have possibilities as joint sealers. But if the cells are sealed, they may burst if the sealer goes into compression; if not sealed, they may absorb water and fail when the water freezes.

Any satisfactory sealing system which is developed will perhaps have to incorporate at least two of the following:

1. The introduction of better materials as joint sealers.
2. The introduction of alternative shapes or forms of the materials.
3. New requirements relating initial joint widths or joint profiles to joint spacing, to climate, and to joint sealing materials.

Initial costs of many of the sealers tested are higher than those now in common use. Nevertheless, the total maintenance cost of replacement of sealant and possibly repair of damaged concrete may more than justify the higher initial cost.

ACKNOWLEDGMENT

Comparative Testing of Joint Sealers
in Sixteen Laboratories

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Bond-ductility, flow, and penetration tests are frequently used to
evaluate compounds for joint and crack sealing in pavements. The
tests are usually run according to Federal Specification SS-R-406c
method 223.11.

It has been observed that laboratories using this procedure do not
always arrive at the same results, and therefore some have rejected
sealers that pass the test in other laboratories. To find out how
different these results could be, 16 laboratories were asked to
participate in the evaluation of bond-ductility, flow, and penetration
tests for joint sealing compounds.

Three hot-poured type rubber-asphalt sealants were used in this
testing program. The material samples, together with special mortar
test blocks for the bond-ductility test, were sent to all participants
from one centralized source. The Federal Specification SS-R-406c
procedure was used, emphasizing certain details in order to have the
test better controlled.

In spite of the careful planning and control the test results vary
considerably between the participants. This is especially noticeable
in the bond-ductility test.

The preliminary conclusions are:

1. The bond-ductility test should be restudied and adjusted to
assure a better reproducibility.
2. The flow test is not an accurate test, but gives reasonably
comparable results.
3. The penetration test appears to give relatively reproducible
results.

●THIS paper is the outcome of a cooperative testing program initiated by the HRB
Committee on Fillers and Sealers for Joints and Cracks in Pavements. Sixteen labora-
tories participated, each testing the same three hot-poured rubber-asphalt sealers of a
type used for joints in cement concrete pavement. The author, as part of the work of
the Joint Highway Research Project of the Massachusetts Institute of Technology, under-
took to assemble and correlate the work of the participants.

Test results of the same sealing material have not always been uniform. In 1951
Robbers and Swanberg (1), using Federal Specification SS-R-406b (May 19, 1947), tested
several hundred specimens of one hot-poured rubber-asphalt sealer and found consider-
able variations in the results. They commented: "It would appear that the testing pro-
cedures are still in a pioneering stage and this also applies, at least in part, to the
specification requirements." Data obtained by nine cooperating laboratories (Group IV,
AASHO, testing in 1950; summarized in (1)) some time ago also show poor agreement
in their tests of identical samples. It has been the author's experience that test values
on sealing compounds in the laboratory are often noticeably higher or lower than those
given by the manufacturer.

OBJECTIVE OF TESTING PROGRAM

The main objective of the testing program was to determine whether different labora-
tories could get reproducible test results. Identical sealer samples were used, and all
laboratories followed Federal Specification SS-S-406c, Method 223.11 with certain

additional refinements. This specification dated February 12, 1952, is practically identical with Federal Specification SS-R-406b. For the details, the reader is referred to the specifications; the additional refinements are given in the Appendix.

SAMPLE PROCUREMENT

Three hot-poured rubber-asphalt sealers were used. The samples and the special cement mortar blocks were distributed by one of the participating laboratories.

TESTS SELECTED

The Committee selected three tests from the specification[1] for use in the cooperative program as follows:

1. Penetration test.
2. Flow test.
3. Bond-ductility test.

The penetration indicates the hardness of a material. A sample of a sealer is penetrated for 5 sec by a cone of specified weight, and the depth of sinking is measured. The test is performed at 77 F. The penetration value should not exceed 0. 90 cm.

The flow test determines potential softening of a sealer in warm weather. A specimen 4 by 6 cm in area and 0. 32 cm thick, is molded on a slightly larger tin panel which is kept for 5 hr at 75 degrees to the horizontal. The test is performed at 140 F. After the test, the change of length of the specimen is measured in cm and expressed as flow. The maximum limit is 0. 5 cm.

The bond-ductility test is the most important of the series. It shows how well the sealing material adheres to the test blocks, as well as the ductility of the compound itself. In this test two specially prepared mortar blocks are set 1 in. apart to form a 1- by 2- by 2-in. space, which is filled with the sealer. An extension machine is used to pull the blocks apart slowly at 0 F, simulating the action of road joints in cold weather. If a sealer passes five cycles it is acceptable.

SPECIFIED PROCEDURAL REQUIREMENTS

All participants were asked to run the tests (see Appendix) in duplicate to check their repeatability in the laboratory. Two bond-ductility specimens were to be poured on each testing day. (The specification calls for molding three bond-ductility specimens for one test.) The results were recorded on standard forms, which also included descriptive questions on the test equipment.

TEST RESULTS

The results are given in Tables 1, 2, and 3. Both average penetration and average flow were obtained from two sets of two specimens each. Data on melting equipment are given in Table 4; on ovens, in Table 5.

Penetration Test Results

The average penetration data of Tables 1, 2, and 3 are summarized in Table 6. Inasmuch as the maximum allowable penetration is 0. 90 cm, and the three samples were below this limit, they all passed the test.

There are considerable differences between the findings of the various laboratories. Thus, for Sample O the difference between the highest and the lowest recorded penetrations is 0. 15 cm. The differences for the other two samples are not as large. There are no unusual values in the readings, and the mean and median are identical. The

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[1]As used in this paper, "the specification" always means Federal Specification SS-R-406c, Method 223. 11, unless otherwise designated.

TABLE 1

SUMMARY OF TEST RESULTS FOR SAMPLE N

Lab. No.	Test Day	Melt Temp. (°F)	Melt Time (min)	Aver. Pen. (cm)	Aver. Flow (cm)	Bond-ductility (cycles) Spec. A	Spec. B
1	1	400	51	0.48	0.15	5	5
	2	400	49	0.48	0.10	5	4
2	1	398	43	0.52	0.18	2	2
	2	398	50	0.52	0.19	3	3
3	1	395	50	0.44	0.15	5	3
	2	395	45	0.46	0.10	5	3'
4	1	400	34	0.44	0.20	0	0
	2	395	32	0.47	0.20	1	0
5	1	400	50	0.47	0.20	5	3
	2	400	50	0.48	0.20	4	4
6	1	385	55	0.53	0	1	1
	2	400	45	0.52	0.20	5	5
7	1	402	50	0.52	0.20	0	0
	2	400	48	0.51	0.20	0	0
8	1	400	28	0.57	0.15	2	5
	2	400	25	0.57	0.20	1	1
9	1	400	49	0.59	0.08	0	0
	2	400	49	0.56	0.08	0	0
10	1	400	39	0.51	0.18	4	4
	2	400	44	0.55	0.20	1	1
11	1	400	45	0.56	0.20	3	3
	2	400	44	0.55	0.20	3	3
12	1	400	26	0.53	0.10	2	1
	2	400	27	0.53	0.10	0	0
13	1	400	35	0.50	0.15	0	3
	2	400	40	0.51	0.15	0	0
14	1	399	47	0.53	0.10	1	5
	2	400	47	0.52	0.10	3	5
15	1	401	50	0.58	0.10	0	0
	2	401	42	0.55	0.20	0	0
16	1	400	35	0.55	0.10	1	4
	2	400	35	0.55	0.15	1	4
Low		385	25	0.44	0	0	
High		402	55	0.58	0.20	5	
Mean		-	43	0.52	0.15	2.1	
Median		-	-	0.52	0.15	-	

TABLE 2

SUMMARY OF TEST RESULTS FOR SAMPLE O

Lab. No.	Test Day	Melt Temp. (°F)	Melt Time (min)	Aver. Pen. (cm)	Aver. Flow (cm)	Bond-ductility (cycles) Spec. A	Spec. B
1	1	400	51	0.84	0.25	5	5
	2	400	49	0.80	0.20	5	4
2	1	395	42	0.80	0.18	5	5
	2	400	73	0.82	0.12	5	5
3	1	395	45	0.75	0.10	5	5
	2	400	45	0.77	0.10	5	5
4	1	400	30	0.75	0.30	5	5
	2	395	32	0.74	0.30	5	5
5	1	400	49	0.76	0.10	4	3
	2	400	50	0.78	0.10	4	4
6	1	400	40	0.80	0	5	5
	2	386	50	0.81	0.10	5	5
7	1	400	47	0.82	0.20	5	5
	2	400	48	0.82	0.10	5	5
8	1	400	26	0.88	0.20	5	5
	2	400	26	0.89	0.05	3	5
9	1	400	52	0.85	0.08	5	5
	2	400	53	0.87	0.15	5	5
10	1	400	47	0.85	0.13	5	5
	2	400	45	0.83	0.18	5	5
11	1	400	45	0.82	0.20	5	5
	2	400	47	0.82	0.20	5	5
12	1	400	30	0.86	0	5	5
	2	400	30	0.86	0	5	5
13	1	400	50	0.87	0.15	5	5
	2	400	35	0.80	0.20	5	5
14	1	400	48	0.81	0	4	5
	2	400	47	0.80	0	5	5
15	1	401	37	0.79	0.10	3	0
	2	399	45	0.79	0.10	3	0
16	1	400	35	0.87	0.10	5	5
	2	400	35	0.86	0.10	5	4
Low		356	26	0.74	0	0	
High		401	73	0.89	0.30	5	
Mean		-	43	0.82	0.13	4.6	
Median		-	-	0.82	0.10	-	

maximum difference between the penetration values obtained on each test day in any one laboratory was 0.07 cm.

The specification does not include reproducibility limits for the cone penetration test of sealing materials. However, as this test is an adaptation of the penetration test for petrolatum (ASTM Designation D 937-49T), the reproducibility limits given in that specification can be used. For penetrations of less than 2.00 cm the maximum allowable deviation from the mean in this test is 0.07 cm. In the tests reported here, all samples exceeded this limit by 0.01 cm. As any penetration between 0 and 0.90 cm is accepted, and the main importance of the test is to give a feeling for the consistency of the sealer, the accuracy of the test seems adequate from a practical standpoint.

A needle penetration test (ASTM Designation D 5) can be used where more exact values are needed. Here the allowable mean deviation changes with the consistency of the material; that is, if the material is soft, a larger deviation is expected. Robbers and Swanberg (1) performed some comparative needle and cone penetration tests, and their results point toward the superiority of the former.

Flow Test Results

The average flow data of Tables 1, 2, and 3 are summarized in Table 7. All specimens passed the flow test, but the results vary considerably from one laboratory to another. Sample O is the most striking example: three laboratories found no flow at all, whereas seven others recorded between 0.20 and 0.30 cm. The test results on the rest of the samples are also uneven. The largest difference between the flow values

TABLE 3

SUMMARY OF TEST RESULTS FOR SAMPLE P

Lab. No.	Test Day	Melt Temp. (°F)	Melt Time (min)	Aver. Pen. (cm)	Aver. Flow (cm)	Bond-ductility (cycles) Spec. A	Spec. B
1	1	400	50	0.56	0.15	5	5
	2	400	48	0.59	0.12	5	5
2	1	400	49	0.62	0.10	5	5
	2	400	44	0.55	0.14	5	5
3	1	400	50	0.53	0.05	1	1
	2	395	50	0.53	0	1	2
4	1	400	30	0.53	0.20	5	5
	2	400	30	0.54	0.25	5	3
5	1	400	50	0.57	0.20	5	5
	2	400	50	0.58	0.10	5	5
6	1	386	50	0.55	0	0	0
	2	400	45	0.55	0	0	5
7	1	402	50	0.58	0.20	5	5
	2	404	50	0.57	0.20	5	5
8	1	400	28	0.64	0.20	5	5
	2	400	28	0.65	0.10	5	5
9	1	400	51	0.63	0	5	5
	2	400	53	0.63	0	2	1
10	1	400	41	0.55	0.10	5	5
	2	400	46	0.55	0.13	5	5
11	1	400	48	0.58	0.20	5	5
	2	400	49	0.58	0.20	5	5
12	1	400	25	0.56	0	5	5
	2	400	25	0.56	0	5	5
13	1	405	50	0.55	0.15	5	5
	2	400	50	0.55	0.20	5	5
14	1	395	50	0.52	0	5	5
	2	400	48	0.54	0	5	5
15	1	401	45	0.56	0.10	0	0
	2	401	38	0.58	0	0	0
16	1	400	35	0.58	0.10	5	5
	2	400	40	0.57	0.10	5	1
Low		386	25	0.52	0	0	
High		405	53	0.65	0.25	5	
Mean		-	44	0.57	0.10	4.0	
Median		-	-	0.57	0.10	-	

TABLE 4

MELTERS USED BY PARTICIPANTS

Lab. No.	Oil Jacket	Melting Pot (in.) Dia.	Ht.	Covered	Bottom Disch.	Type Heat	Agitation Hand	Mech.
1	Yes	4.4	3.1	No	Yes	Elec.		120 rpm
2	Yes	4	5	No	No	Gas	X	
3	Yes	9	5.5	Yes	No	Elec.	X	
4	Yes	4.5	5.5	No	Yes	Gas		60 rpm
5	Yes	4	5.5	No	No	Gas	X	
6	Yes	4	5	No	Yes	Gas		60 rpm
7	Yes	4.5	5.5	No	No	Gas	X	
8	Yes	3.8	5.3	No	No	Elec.	X	
9	Yes	3.5	7	No	No	Elec.		25 rpm
10	Yes	3.5	7	Yes	Yes	Gas		32 rpm
11	Yes	4	6	Yes	Yes	Gas		25 rpm
12	Yes	3.5	7	No	Yes	Elec.		30 rpm
13	Yes	3.6	7.5	No	Yes	Gas		30 rpm
14	Yes	3.5	7.8	No	No	Elec.		20 rpm
15	Yes	4	5.6	Yes	No	Gas	X	
16	Yes	3.5	7.5	Yes	Yes	Elec.		31 rpm

TABLE 5

OVENS USED BY PARTICIPANTS

Lab. No.	Inside dim. (in.) H	W	L	Ventilation Natural Draft	Forced Draft	Type of heating elements
1	12	12	24	x		Nickel-chromium ribbon, bottom
1	19.8	17	14	x		Two 225-w coils
3	19	14	19	x		Electric coils, bottom
4	19.8	17	14	x		Five 165-w elements, bottom
5	9.5	12	10	x		Resistance type
6	11.5	10.5	12	x		Electrical (open coil)
7	12.3	12.3	12.3		x	Two 250-w and one 500 -w element
8	14	16	16	x		Electric coils, bottom
9	13	14	13		x	Nickel-chromium
10	13	13	13		x	Electric coils, 2000-w, top
11	17	19	14		x	Nickel-chromium coils
12	9	11	9	x		Electric
13	14	12	12	x		Electric coils
14	12	11	12		x	Electric coils
15	13.3	12	12	x		Chromel wire on mica
16	19.8	17	14		x	Four helical coils, 300-w each

TABLE 6

PENETRATION TEST SUMMARY

Sample	Penetration Range (cm)	Max. Diff. (cm)	Mean (cm)	Median (cm)	Max. Dev. from Mean (cm)
N	0.44-0.58	0.14	0.52	0.52	0.080
O	0.74-0.89	0.15	0.82	0.82	0.080
P	0.52-0.65	0.13	0.57	0.57	0.080

TABLE 7

FLOW TEST SUMMARY

Sample	Flow Value Limits (cm)	Arithmetic Mean (cm)	Median (cm)	Max. Dev. from Mean (cm)
N	0 - 0.20	0.15	0.15	0.15
O	0 - 0.30	0.13	0.10	0.17
P	0 - 0.25	0.10	0.10	0.15

TABLE 8

BOND-DUCTILITY PERFORMANCE OF FOUR-SPECIMEN GROUPS

Sample	Number of Laboratories Passed	Rejected	Probability of Passing
N	1	15	0.063
O	14	2	0.875
P	12	4	0.750

obtained on each test day in any one laboratory was 0.20 cm. Consequently, if a sealer has a flow near the allowable limit of 0.50 cm, it may be accepted at one time and rejected at another. There is no set standard of reproducibility for this test.

Bond-Ductility Test Results

There are various ways of looking at the bond-ductility test results given in Tables 1, 2, and 3. If the criterion is used that a sealer must pass five cycles in three out of four tests, grouping four specimens from the two separate days, the results are as given in Table 8, from which it is concluded that Sample N is inferior and Sample O performed best.

If the total number of specimens passed is contrasted with the total number of failures, the results given in Table 9 are obtained. Here it is found that Sample N's chances of passing have more than doubled, while those of Sample O are lower. Since the statistical sample population in Table 9

is 64 compared to 16 in Table 8, the re-
sults should be closer to reality. Tables
8 and 9 distinguish only between specimens
that passed the required five cycles and
those that failed sooner. A still better
comparison between the results of different
laboratories may be obtained if the number
of cycles for each of them is totaled, as
in Figures 1, 2, and 3. The possible max-
imum in all columns is 20, if every speci-
men passed five cycles.

Sample N, the least satisfactory of the
lot, passed 19 cycles in one laboratory
and none in three others. The median
value is 10 and the arithmetic mean 8.5
cycles (Fig. 1).

TABLE 9

NUMBER OF SPECIMENS PASSED AND REJECTED
IN THE BOND-DUCTILITY TEST

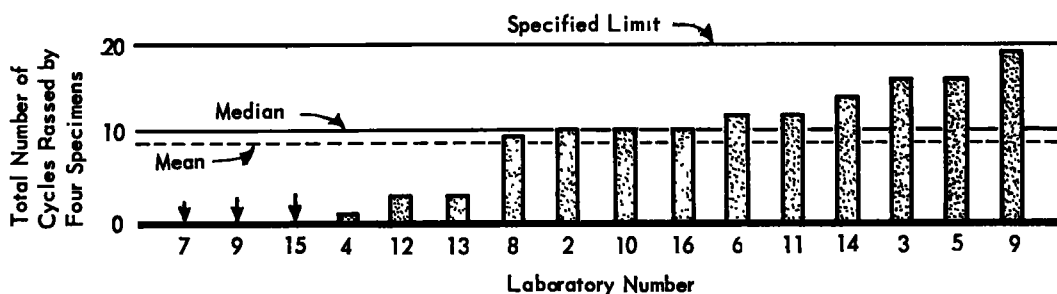| Sample	Passed	Rejected	Probability of Passing
N	11	53	0.172
O	52	12	0.813
P	49	15	0.766

Figure 1. Total number of cycles passed in the bond-ductility test by four specimens
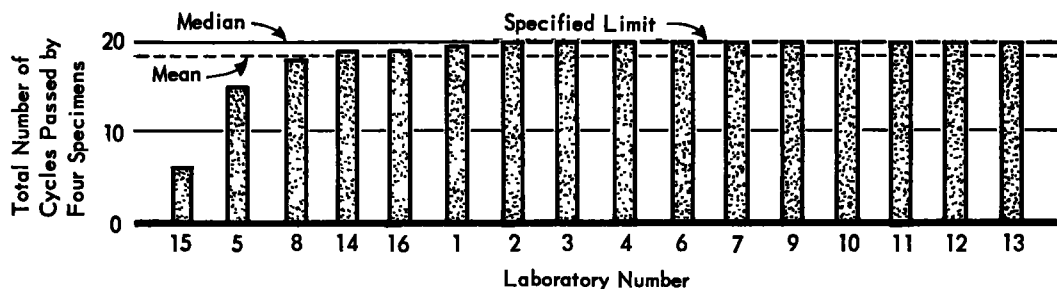of Sample N in each laboratory.

Figure 2. Total number of cycles passed in the bond-ductility test by four specimens
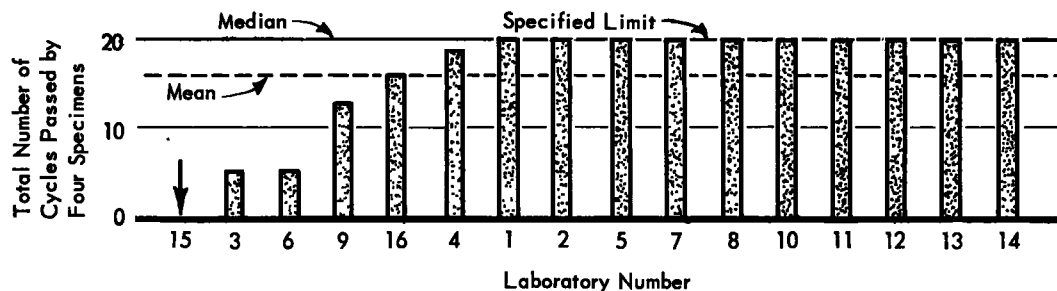of Sample O in each laboratory.

Figure 3. Total number of cycles passed in the bond-ductility test by four specimens
of Sample P in each laboratory.

Figure 2 shows the cycle totals for Sample O, which performed better than the others. As the bond-ductility test is not continued until failure in all cases, the right side of the figure is flat. If each specimen had been tested to the end, a distribution pattern similar to Figure 1 probably would result.

Figure 3 shows the cycle comparison for Sample P. Three extreme values are found at the left of the figure, and there is a four-unit difference between the median and the mean. As in Figure 2, the actual range of values cannot be determined because of the five-cycle test limit.

Figure 4 compounds the data from Figures 1, 2 and 3. It shows which laboratories tend to be high and which low. Laboratory 15[2] is the only obvious extreme, although the range between the results of the others is considerable: the lowest passed 33 cycles and the highest 58.

The consistency of the results obtained from the same specimen within the same laboratory is generally defined as "repeatability." This, too, seems poor. In a number of cases one specimen of a lot passed five cycles whereas another of the same sample passed only one (see Table 1, Laboratories 6, 8, and 14; and Table 3, Laboratories 6, 9, and 16). Lesser variations occur more often. The specification sets no limits for reproducibility and repeatability.

The differences in the tests of Sample N are striking: the average of the three lowest laboratories is zero, and that of the three highest is 17 cycles. For the best of the three samples (Fig. 2) the difference is much smaller (the comparable values are 13 and 20), which indicates that the reproducibility of the test improves with the quality of the sealer. The five-cycle limit for each specimen explains this difference. However, the worst sample gives the best indication of the actual variations in the test results. As these were scattered over almost the entire possible range, it is safe to conclude
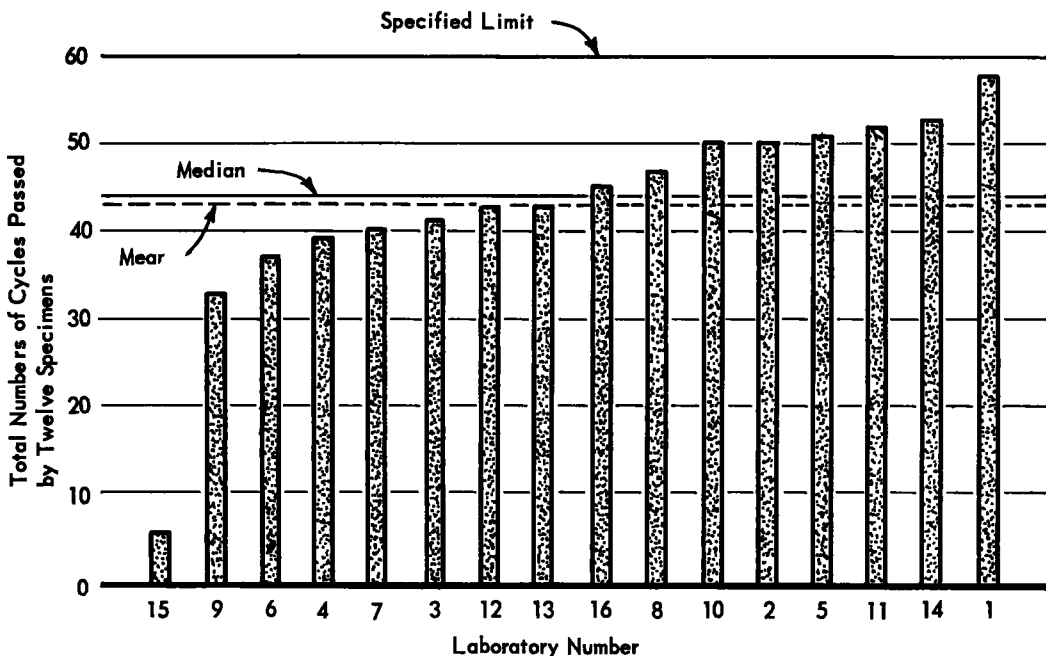

Figure 4. Total number of cycles passed in the bond-ductility test by twelve specimens of Samples N, O, and P in each laboratory.

[2]The summary of the test results was sent to all participants before this paper was written. Laboratory 15 commented that the bond failures which they found occurred mostly in the mortar, not in the sealer. Their specimens had been stored at 0 F for eight weeks before testing.

that the bond-ductility test has a very poor theoretical reproducibility.

COMMENTS ON TESTING PROCEDURES AND EQUIPMENT

TABLE 10

TYPE OF VENTILATION AND FLOW CORRELATION

Type of Oven Ventilation	Mean Deviation		
	Sample N	Sample O	Sample P
Natural draft	0.041	0.072	0.068
Forced draft	0.048	0.057	0.069

There was no known procedural deviation from the Federal Specification. The additional limits on heating time and temperature (see Appendix) were exceeded slightly by several participants. One was low on melting time and another on melting temperature. It is not known how this has affected the test results. No trend was observed in the data, and the deviators were left in the comparison.

One laboratory stored its bond-ductility specimens for eight weeks at 0 F before testing. (The same laboratory complained about bond failures in mortar, not between sealer and block surface.) The specification does not limit cold-room storage time. The influence of this upon the results is not known, but it might be a loophole in the test procedure.

The test equipment varied widely. Tables 4 and 5 summarize the melting kettles and heating ovens used. It was nearly impossible to make a quantitative analysis of how the equipment affected the results. The ovens with forced draft ventilation were compared with those of natural draft in Table 10, from which no definite conclusions can be drawn. The table was calculated by dividing each sample into two groups—those that were put into natural and those that were put into forced draft ovens.

In a similar statistical comparison on melting kettles, the penetration test showed a slightly better reproducibility with samples coming from the mechanically agitated melters.

LABORATORY TESTS AND FIELD CONDITIONS

There are two prime considerations for laboratory tests of this type as follows:

1. The test procedure should be simple to follow, thorough in detail, and give reproducible results.
2. The test procedure should either simulate field conditions or have a good correlation with them.

It is questionable whether all the present tests for sealers fulfill these requirements. For example, in the present bond-ducility test, one set of conditions simulates a wide variety of joints (2) and other factors (2, 3, 4, 5), especially climate. Simple observations and calculations by the author indicate that the test is mild compared to the strains and bond conditions under which many sealers are expected to operate.

A theoretical and practical analysis should therefore be made of the performance that is required of a sealer. Different types of joints, various climates, and other factors, should be taken into consideration. With this information, the undependable tests could be re-designed to give better and more practical results.

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions based on the results of testing three hot-poured rubber-asphalt sealers are as follows:

1. The reproducibility of the cone penetration test is not good, but it is probably adequate for practical purposes.
2. The results of the flow test vary widely. The test is not accurate.
3. The bond-ductility test shows poor actual repeatability and reproducibility in the case of lower-quality sealers.
4. The apparent reproducibility of the bond-ductility test increases with the improvement in the bond-ductility qualities of the sealer. This is due to discontinuing the testing after five cycles.

In view of the differences in the joint sealer test results described in this paper, the following recommendations based on testing and a limited literature study might be of interest:

1. The present test procedures should be studied thoroughly, all possible loopholes eliminated, and vague statements made more specific.
2. The reproducibility of the bond-ductility and the flow tests should be improved.
3. A change from cone penetration to the regular needle penetration for hot-poured rubber-asphalt sealers would increase the test reproducibility and would be familiar to more people in the sealing and related fields.

Added to the foregoing recommendations are the following opinions of the author:

1. The first in line for redesign is not the test procedure (to increase reproducibility) but the specification requirements.
2. The bond-ductility test should be re-examined in the light of the great variety of field requirements. A similar suggestion can be made for the flow test.

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Appendix

INSTRUCTIONS TO PARTICIPATING LABORATORIES, COMPARATIVE TESTING OF JOINT SEALERS

Subject

Highway Research Board Committee D-3 Joint Sealer Cooperative Program.

Testing Method

Method 223.11 of Federal Specification SS-R-406c will be used for this testing. It is the proposal of Committee D-3 that the following details be strictly adhered to by participating laboratories.

Details of Testing

1. <u>Laboratory Melter.</u>—For these tests, each laboratory will use its own melter. The melter must, however, be of the double-boiler type and means provided for adequate, continuous stirring of the sample as it is heated to pouring consistency. Wherever possible, a melter with a bottom discharge opening is preferred for this testing.

2. <u>Pouring Temperature.</u>—Specimens for the flow, penetration, and bond tests should be poured after the well-blended sealer melt reaches 400 ± 5 F.

3. <u>Oil Bath Temperature.</u>—The oil bath temperature should be maintained at 440 ± 5 F during the entire sample preparation.

4. <u>Sample Preparation.</u>—(a) 600 grams of sample should be taken for each pour, as outlined in the Federal method. (b) As outlined in the Federal method, 200 grams of sealer should be added to the hot melter (oil bath 440 ± 5 F). The remaining 400 grams should be added in 50-gram increments.

5. <u>Pouring Test Specimens.</u>—When the sealer melt reaches the pouring temperature (400 ± 5 F), duplicate specimens for the flow, penetration, and bond tests will be poured in that order. For bottom discharge melters, 2-ounce ointment tin will be poured initially and discarded. The test specimens will then be poured as outlined above.

6. <u>Melting Time.</u>—The rate of heating should be so controlled that the pouring temperature is reached in 40 min. ± 10 min. from the addition of the first 200 grams of sealer to the melter. (The bath temperature should be 440 F when the first 200 grams of material is added and should be controlled at 440 F.) The sealer will be kept in the pot at least 30 min, regardless of when the pouring temperature is reached.

7. <u>Method of Test.</u>—The flow, penetration, and bond tests will be run in accordance with the Federal methods described in 223.11. The oven and melter used for the tests should be fully described on the data sheet. The blocks supplied have been surface ground. They should, however, be redried and surface brushed before being used.

8. <u>Number of Tests.</u>—Each participating laboratory will pour each of the three selected sealers on two different days and the tests will be run in duplicate. (Two bond test specimens will be run as per the Federal specification, rather than four. If four specimens were poured, 600 grams of material would not be sufficient.)

9. <u>Reporting of Results.</u>—All Data should be reported on the enclosed reporting form.

Report Form

	Temp.	Time	Penetration	Flow	Bond
Sample N, Day 1	x	x	xx avg	xx avg	xx
Day 2	x	x	xx avg	xx avg	xx
Sample O, Day 1	x	x	xx avg	xx avg	xx
Day 2	x	x	xx avg	xx avg	xx
Sample P, Day 1	x	x	xx avg	xx avg	xx
Day 2	x	x	xx avg	xx avg	xx

Notes: —Each x under "time" represents the time in minutes
it takes to bring the sample up to the pouring temperature from
the time the first 200 g of material are placed in the melter.
Each x under "Temp." represents the actual temperature of
material at time of pouring test specimens.
Each x under "Flow" denotes the greatest flow point on the
panel, not an average of both sides of the panel.
Each x under "Penetration" denotes an average of at least 3
penetrations on each tin.
Each x under "Bond" represents a specimen running 5 cycles.
In the event of bond failure, the last previous cycle in which it
passed should be so noted.

HRB:OR-211

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