

Guide to Sealing Joints in Concrete Structures

Reported by ACI Committee 504*

Guy S. Puccio
Chairman

T. Michael Jackson
Secretary

Milton D. Anderson
Bert E. Colley
John P. Cook
Robert V. Costello
Edward R. Fyfe
Frank D. Gaus

Charles S. Gloyd
Arthur Hockman
George Horeczko
Vincent Kazakovich
Oswin Keifer, Jr.
Frank Klemm
Joseph F. Lamond

Peter Marko
Joseph A. McElroy
Leroy T. Ohler
Chris Seibel, Jr.
Peter Smith
Stewart C. Watson

*The Committee wishes to recognize the important contribution of the current chairman, Sherwood Spells, to the development of this guide.

Most joints, and some cracks in concrete structures, require sealing against the adverse effects of environmental and service conditions. This report is a guide to better understanding of the properties of joint sealants and to where and how they are used in present practice.

Described and illustrated are: The functioning of joint sealants; required properties, available materials and applicable specifications for field-molded sealants and preformed sealants such as waterstops, gaskets, or compression seals; determination of joint movements, widths, and depths; outline details of joints and sealants used in general structures, fluid containers, and pavements; methods and equipment for sealant installation including preparatory work; performance of sealants; and methods of repairing defective work or maintenance resealing. Finally, improvements needed to insure better joint sealing in the future are indicated.

New developments in field-molded and preformed sealants and their use are described together with means of measuring joint movements. Appendix C provides a list of specifications and their sources.

Keywords: bridge decks; bridges (structures); buildings; compression seals; concrete construction; concrete dams; concrete panels; concrete pavements; concrete pipes; concrete slabs; concretes; construction joints; control joints; cracking (fracturing); gaskets; isolation joints; joint fillers; joint scalers; joints (junctions); linings; mastics; parting agents; precast concrete; reinforced concrete; repairs; sealers; specifications; tanks (containers); thermoplastic resins; thermosetting resins; walls.

CONTENTS

Chapter 1-General, p. 504R-2

- 1.1-Background
- 1.2-Purpose
- 1.3-Why joints are required
- 1.4-Why sealing is needed
- 1.5-Joint design as part of overall structural design
- 1.6-Types of joints and their function
- 1.7-Joint configurations

ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in designing, planning, executing, or inspecting construction, and in preparing specifications. Reference to these documents shall not be made in the Project Documents. If items found in these documents are desired to be part of the Project Documents, they should be incorporated directly into the Project Documents.

Chapter 2-How joint sealants function, p. 504R-4

- 2.1-Basic function of sealants
- 2.2-Classification of sealants
- 2.3-Behavior of sealants in butt joints
- 2.4-Malfunction of sealants
- 2.5-Behavior of sealants in lap joints
- 2.6-Effect of temperature
- 2.7-Shape factor in field-molded sealants
- 2.8-Function of bond breakers and backup materials
- 2.9-Function of fillers in expansion joints
- 2.10-Function of primers

Chapter 3-Sealant materials, p. 504R-12

- 3.1-General
- 3.2-Required properties of joint sealants
- 3.3-Available materials
- 3.4-Field-molded sealants
- 3.5-Preformed seals

Chapter 4-Joint movement and design, p. 504R-25

- 4.1-Discussion
- 4.2-Determination of joint movements and locations
- 4.3-Selection of butt joint widths for field-molded sealants
- 4.4-Selection of butt joint shape for field-molded sealants
- 4.5-Selection of size of compression seals for butt joints
- 4.6-Limitations on butt joint widths and movements for various types of sealants
- 4.7-Lap joint sealant thickness
- 4.8-Shape and size of rigid waterstops
- 4.9-Shape and size of flexible waterstops
- 4.10-Shape and size of gaskets and miscellaneous seals
- 4.11-Measurement of joint movements

Chapter 5-Joint details, p. 504R-31

- 5.1-Introduction
- 5.2-Structures
- 5.3-Slabs on grade, highway, and airports
- 5.4-Construction and installation considerations

This supercedes ACI 504R-77.

Copyright © 1990, American Concrete Institute.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by an electronic or mechanical device, printed or written or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietor.



Documents

Document Sharing Hub

Chapter 6-Installation of sealants, p. 504R-31

- 6.1-Introduction
- 6.2-Joint construction with sealing in mind
- 6.3-Preparation of joint surfaces
- 6.4-Inspection of readiness to seal
- 6.5-Priming, installation of backup materials and bond breakers
- 6.6-Installation of field-molded sealants, hot applied
- 6.7-Installation of field-molded sealants, cold applied
- 6.8-Installation of compression seals
- 6.9-Installation of preassembled devices
- 6.10-Installation of waterstops
- 6.11-Installation of gaskets
- 6.12-Installation of fillers
- 6.13-Neatness and cleanup
- 6.14-Safety precautions

Chapter 7-Performance, repair, and maintenance of sealants, p. 504R-36

- 7.1-Poor performance
- 7.2-Repairs of concrete defects and replacement of sealants
- 7.3-Normal maintenance

Chapter 8-Sealing in the future and concluding remarks, p. 504R-37

- 8.1-What is now possible
- 8.2-Advancements still needed

Chapter 9-References, p. 504R-37

Appendix A-Layman's glossary for joint sealant terms, p. 504R-38

Appendix B-Key to symbols used in figures, p. 504R-40

Appendix C-Sources of specifications, p. 504R-41

CHAPTER I-GENERAL

1.1-Background

This report is an update of the committee report originally issued in 1970 and revised in 1977.¹

Nearly every concrete structure has joints (or cracks) that must be sealed to insure its integrity and serviceability. It is a common experience that satisfactory sealing is not always achieved. The sealant used, or its poor installation, usually receives the blame, whereas often there have been deficiencies in the location or the design of the joint that would have made it impossible for any sealant to have done a good job.

1.2-Purpose

The purpose of this guide is to show that by combining the right type of sealant with proper joint design for a particular application and then carefully installing it, there is every prospect of successfully sealing the joint and keeping it sealed. This report is a guide to what can be done rather than a standard practice, because in most instances there is more than one choice available. Without specific knowledge of the structure, its design, service use, environment, and economic constraints, it is impossible to prescribe a "best joint design" or a "best sealant". The information contained in this guide is, however, based on current practices and experience judged sound by the committee and used by one or more of the many reputable organizations consulted during its compilation. It should therefore be useful in making an enlightened choice of a suitable joint sealing system and to insure that it is then properly detailed, specified, installed, and maintained.

No attempt has been made to reference the voluminous literature except for those papers necessary to an understanding of the subject background. The present state of the art of joint sealing and identification of needed research may be found in the proceedings of the 1st and 2nd World Congresses on Joint Sealing and Bearing Systems held in 1981 and 1986.^{2,3} A glossary of terms that may not be generally familiar is provided in the appendix.

1.3-Why joints are required

Concrete normally undergoes small changes in dimensions as a result of exposure to the environment or by the imposition or maintenance of loads. The effect may be permanent contractions due to, for example: initial drying, shrinkage, and irreversible creep. Other effects are cyclical and depend on service conditions such as environmental differences in humidity and temperature or the application of loads and may result in either expansions or contractions. In addition, abnormal volume changes, usually permanent expansions, may occur in the concrete due to sulfate attack, alkali-aggregate reactions, and certain aggregates, and other causes.

The results of these changes are movements, both permanent and transient, of the extremities of concrete structural units. If, for any reason, contraction movements are excessively restrained, cracking may occur within the unit. The restraint of expansion movement may result in distortion and cracking within the unit or crushing of its end and the transmission of unanticipated forces to abutting units. In most concrete structures these effects are objectionable from a structural viewpoint. One of the means of minimizing them is to provide joints at which movement can be accommodated without loss of integrity of the structure.

There may be other reasons for providing joints in concrete structures. In many buildings the concrete serves to support or frame curtainwalls, cladding, doors, windows, partitions, mechanical and other services. To prevent development of distress in these sections it is often necessary for them to move to a limited extent independently of overall expansions, contractions and deflections occurring in the concrete. Joints may also be required to facilitate construction without serving any structural purpose.

1.4-Why sealing is needed

The introduction of joints creates openings which must usually be sealed in order to prevent passage of gases, liquids or other unwanted substances into or through the openings.

In buildings, to protect the occupants and the contents, it is important to prevent intrusion of wind and rain. In tanks, most canals, pipes and dams, joints must be sealed to prevent the contents from being lost.

Moreover, in most structures exposed to the weather the concrete itself must be protected against the possibility of damage from freezing and thawing, wetting and drying, leaching or erosion caused by any concentrated or excessive influx of water at joints. Foreign solid matter, including ice, must be prevented from collecting in open joints; otherwise, the joints cannot close freely later. Should this happen, high stresses may be generated and damage to the concrete may occur.

In industrial floors the concrete at the edges of joints often needs the protection of a filler or sealant between armored faces capable of preventing damage from impact of concentrated loads such as steel-wheeled traffic.

In recent years, concern over the spread of flames, smoke and toxic fumes has made the fire resistance of joint sealing systems a consideration, especially in high-rise buildings.

The specific function of sealants is to prevent the intrusion of liquids (sometimes under pressure), solids or gases, and to protect the concrete against damage. In certain applications secondary functions are to improve thermal and acoustical installations, damp vibrations or prevent unwanted matter from collecting in crevices. Sealants must often perform their prime function, while subject to repeated contractions and expansions as the joint opens and closes and while exposed to heat, cold, moisture, sunlight, and sometimes, aggressive chemicals. As discussed in [Chapters 2, 3 and 6](#), these conditions impose special requirements on the properties of the materials and the method of installation.

In most concrete structures all concrete-to-concrete joints (contraction, expansion and construction), and the periphery of openings left for other purposes require sealing. One exception is contraction joints (and cracks) that have very narrow openings, for example, those in certain short plain slab or reinforced pavement designs. Other exceptions are certain construction joints, for example, monolithic joints not subject to fluid pressure or joints between precast units used either internally or externally with intentional open draining joints.

1.5-Joint design as part of overall structural design

In recent years it has become increasingly recognized that there is more to providing an effective seal at a joint than merely filling the “as constructed” gap with an impervious material. The functioning of the sealant, described in [Chapter 2](#), depends as much on the movement to be accommodated at the joint and on the shape of the joint, as on the physical properties of the sealant. Joint design, which broadly covers the interrelationship of these factors, is discussed in some detail in [Chapter 4](#) since it should be an important, sometimes governing, consideration in the design of most concrete structures. It is considered beyond the scope of this guide on sealing joints to venture into the whole field of volume change in concrete and the structural considerations that determine the location and movement of joints. It is, however, pertinent to point out that many years of experience in

trying to keep joints sealed indicate that joint movements may vary widely from those postulated by theory alone.

There are probably as many “typical details” of joints in existence as there are structures incorporating them. Faced with the problem of illustrating, from the viewpoint of how they can be sealed, the various types of joints and their uses, it appeared best to present them in schematic form in [Chapter 5](#) to bring out the principles involved for each of the three major groups of application to concrete:

1. Structures not under fluid pressure (most buildings, bridges, storage bins, retaining walls, etc.).
2. Containers subject to fluid pressure (dams, reservoirs, tanks, canal linings, pipe lines, etc.).
3. Pavements (highways and airfield).

From both the structural and sealant viewpoint, irrespective of design detail and end use, all the joints may be classified according to their principal function and configuration.

1.6-Types of joints and their function

1.6.1 Contraction (control) joints-These are purposely made planes of weakness designed to regulate cracking that might otherwise occur due to the unavoidable, often unpredictable, contraction of concrete structural units. They are appropriate only where the net result of the contraction and any subsequent expansion during service is such that the units abutting are always shorter than at the time the concrete was placed. They are frequently used to divide large, relatively thin structural units, for example, pavements, floors, canal linings, retaining and other walls into smaller panels. Contraction joints in structures are often called control joints because they are intended to control crack location.

Contraction joints may form a complete break, dividing the original concrete unit into two or more units. Where the joint is not wide, some continuity may be maintained by aggregate interlock. Where greater continuity is required without restricting freedom to open and close, dowels, and in certain cases steps or keyways, may be used. Where restriction of the joint opening is required for structural stability, appropriate tie bars or continuation of the reinforcing steel across the joint may be provided.

The necessary plane of weakness may be formed either by partly or fully reducing the concrete cross section. This may be done by installing thin metallic, plastic or wooden strips when the concrete is placed or by sawing the concrete soon after it has hardened.

1.6.2 Expansion (isolation) joints-These are designed to prevent the crushing and distortion (including displacement, buckling and warping) of the abutting concrete structural units that might otherwise occur due to the compressive forces that may be developed by expansion, applied loads or differential movements arising from the configuration of the structure or its settlement. They are frequently used to isolate walls from floors or roofs; columns from floors or cladding; pavement slabs and decks from bridge abutments or piers; and in other locations where restraint or transmission of secondary forces is not desired. Many designers consider it good practice to place such joints where walls or slabs change direction as in L-, T-, Y- and U shaped structures and where different cross sections develop. Expansion joints in structures are often called isolation joints because they are

intended to isolate structural units that behave in different ways.

Expansion joints are made by providing a space for the full cross section between abutting structural units when the concrete is placed through the use of filler strips of the required thickness, bulkheading or by leaving a gap when precast units are positioned. Provision for continuity or for restricting undesired lateral displacement may be made by incorporating dowels, steps or keyways.

1.6.3 Construction joints—These are joints made at the surfaces created before and after interruptions in the placement of concrete or through the positioning of precast units. Locations are usually predetermined by agreement between the design professional and the contractor, so as to limit the work that can be done at one time to a convenient size with the least impairment of the finished structure, though they may also be necessitated by unforeseen interruptions in concreting operations. Depending on the structural design they may be required to function later as expansion or contraction joints having the features already described, or they may be required to be monolithic; that is, with the second placement soundly bonded to the first to maintain complete structural integrity. Construction joints may run horizontally or vertically depending on the placing sequence required by the design of the structure.

1.6.4 Combined and special purpose joints—Construction joints (see Section 1.6.3) at which the concrete in the second placement is intentionally separated from that in the preceding placement by a bond-breaking membrane, but without space to accommodate expansion of the abutting units, also function as contraction joints (see Section 1.6.1). Similarly, construction joints in which a filler displaced, or a gap is otherwise formed by bulkheading or the positioning of precast units, function as expansion joints (see Section 1.6.2). Conversely, expansion joints are often convenient for forming nonmonolithic construction joints. Expansion joints automatically function as contraction joints, though the converse is only true to an amount limited to any gap created by initial shrinkage.

Hinge joints are joints that permit hinge action (rotation) but at which the separation of the abutting units is limited by tie bars or the continuation of reinforcing steel across joints. This term has wide usage in, but is not restricted to, pavements where longitudinal joints function in this manner to overcome warping effects while resisting deflections due to wheel loads or settlement of the subgrade. In structures, hinge joints are often referred to as articulated joints.

Sliding joints may be required where one unit of a structure must move in a plane at right angles to the plane of another unit, for example, in certain reservoirs where the walls are permitted to move independently of the floor or roof slab. These joints are usually made with a bond-breaking material such as a bituminous compound, paper or felt that also facilitates sliding.

1.6.5 Cracks—Although joints are placed in concrete so that cracks do not occur elsewhere, it is extremely difficult to prevent occasional cracks between joints. As far as sealing is concerned, cracks may be regarded as contraction joints of irregular line and form. Treatment of cracks is considered in Section 7.2.2.

1.7-Joint configurations

In the schematic joint details for various types of concrete structures shown in Chapter 5, two basic configurations occur from the standpoint of the functioning of the sealant. These are known as butt joints and lap joints.

In butt joints, the structural units being joined abut each other and any movement is largely at right angles to the plan of the joint. In lap joints, the units being joined override each other and any relative movement is one of sliding. Butt joints, and these include most stepped joints, are by far the most common. Lap joints may occur in certain sliding joints (see Section 1.6.4), between precast units or panels in curtainwalls, and at the junctions of these and of cladding and glazing with their concrete or other framing. As explained in Chapter 2, the difference in the mode of the relative movement between structural units at butt joints and lap joints, in part, controls the functioning of the sealant. In many of the applications of concern to this guide, pure lap joints do not occur, and the functioning of the lap joint is in practice a combination of butt and lap joint action.

From the viewpoint of the sealant, two sealing systems should be recognized. First, there are open surface joints, as in pavements and buildings in which the joint sealant is exposed to outside conditions on at least one face. Second, there are joints, as in containers, dams, and pipe lines, in which the primary line of defense against the passage of water is a sealant such as a waterstop or gasket buried deeper in the joint. The functioning and type of sealant material that is suitable and the method of installation are affected by these considerations.

In conclusion, two terms should be mentioned since they are in wide, though imprecise use. Irrespective of their type or configuration, joints are often spoken of as “working joints” where significant movement occurs and as “nonworking joints” where movement does not occur or is negligible.

CHAPTER 2-HOW JOINT SEALANTS FUNCTION

2.1-Basic function of sealants

To function properly, a sealant must deform in response to opening or closing joint movements without any other change that would adversely affect its ability to maintain the seal. The sealant material behaves in both elastic and plastic manners. The type and amount of each depends on: the movement and rate of movement occurring; installation and service temperatures; and the physical properties of the sealant material concerned, which in service is either a solid or an extremely viscous liquid.

2.2-Classification of sealants

Sealants may be classified into two main groups. These are as follows:

1. Field-molded sealants that are applied in liquid or semi-liquid form, and are thus formed into the required shape within the mold provided at the joint opening.
2. Performed sealants that are functionally preshaped, usually at the manufacturer's plant, resulting in a minimum of site fabrication necessary for their installation.

2.3-Behavior of sealants in butt joints

As a sealed butt joint opens and closes, one of three functional conditions of stress can exist. These are:

1. The sealant is always in tension. Some waterstops [Fig. 1 (2A)] function to a large degree in this way though compressive forces may be present at their sealing faces and anchorage areas.
2. The sealant is always in compression. This principle, as illustrated in Fig. 1 (1A, B, C), is the one on which compression seals and gaskets are based.
3. The sealant is cyclically in tension or compression. Most field-molded and certain preformed sealants work in this way. The behavior of a field-molded sealant is illustrated in Fig. 2 (1A, B, C) and an example of a preformed tension-compression seal is shown in Fig. 9 (4).

A sealant that is always in tension presupposes that the sealant was installed when the joint was in its fully closed position so that thereafter, as the joint opens and closes, the sealant is always extended. This is only possible with preformed sealants such as waterstops which are buried in the freshly mixed concrete and have mechanical end anchors. Field-molded sealants cannot be used this way and the magnitude of the tension effects shown in Fig. 2 (1B) would likely lead to failure as the joint opened in service. Most sealing systems used in open surface joints are therefore designed to function under either sealant in compression or a condition of cyclically in compression and tension to take best advantage of the properties of the available sealant materials and permit ease of installation.

2.4-Malfunions of sealants

Malfunction of a sealant under conditions of stress consists of a tensile failure within the sealant or its connection to the joint face. These are known as cohesive and adhesive failures, respectively.

In the case of preformed sealants that are intended to be always in compression, malfunctioning usually results in failure to generate sufficient contact pressure with the joint faces. This leads to the defects shown in Fig. 3 (1). This figure also shows defects in water stops. Splits, punctures or leakage at the anchorage may also occur with strip (gland) seals.

Malfunctioning of a field-molded sealant, intended to function cyclically in tension or compression, may develop with repetitive cycles of stress reversal or under sustained stress at constant deformation. The resulting failure will then be shown as one of the defects illustrated in Fig. 4.

Where secondary movements occur in either or both directions at right angles to the main movement, including impact at joints under traffic, shear forces occur across the sealants. The depth (and width) of the sealant required to accommodate the primary movement can more than provide any shear resistance required.

2.5 Behavior of sealants in lap joints

The sealant as illustrated in Fig. 2 (2A, B, C) is always in shear as the joint opens and closes. Tension and compression effects may, however, be added in the modified type of lap joint used in many building applications.

2.6-Effect of temperature

Changes in temperature between that at installation and the maximum and minimum experienced in service affect sealant behavior. This is explained by reference to Fig. 5.

The service range of temperature that affects the sealant is not the same as the ambient air temperature range. It is the actual temperature of the units being joined by the sealant that govern the magnitude of joint movements that must be accommodated by the sealant. By absorption and transfer of heat from the sun and loss due to radiation, etc., depending on the location, exposure, and materials being joined, the difference between service range of temperature and the range of ambient air temperature can be considerable.

For the purpose of this guide, the service range or temperatures has been assumed to vary from -20 to + 130 F (-29 to + 54 C) for a total range of 150 F (83C). In very hot or cold climates or where the joint is between concrete and another material that absorbs or loses heat more readily than concrete, the maximum and minimum values may be greater. This is particularly true in building walls, roofs and in pavements. On the other hand, inside a temperature-controlled building or in structures below ground the range of service temperatures can be quite small. This applies also to containers below water line. However, where part of a container is permanently out of the water, or is exposed by frequent dewatering, the effects of a wider range of temperatures must be taken into account.

The rate of movement due to temperature change for short periods (ie: an hr, a day) is quite as important as the total movement over a year. Sealants generally perform better, that is, respond to and follow joint opening and closing when this movement occurs at a slow and uniform rate. Unfortunately, joints in structures rarely behave this way; where restraint is present, sufficient force to cause movement must be generated before any movement occurs. When movement is inhibited due to frictional forces, it is likely to occur with a sudden jerk that might rupture a brittle sealant. Flexibility in the sealant over a wide range of temperatures is therefore important, particularly at low temperatures where undue hardening or loss of elasticity occurs with many materials that would otherwise be suitable as sealants. Generally all materials perform better at higher temperatures, though with certain thermoplastics softening may lead to problems of sag, flow and indentation.

Furthermore, in structures having a considerable number of similar joints in series, for example, retaining walls, canal linings and pavements, it might be expected that an equal share of the total movement might take place at each joint. However, one joint in the series may initially take more movement than others and therefore the sealant should be able to handle the worst combination.

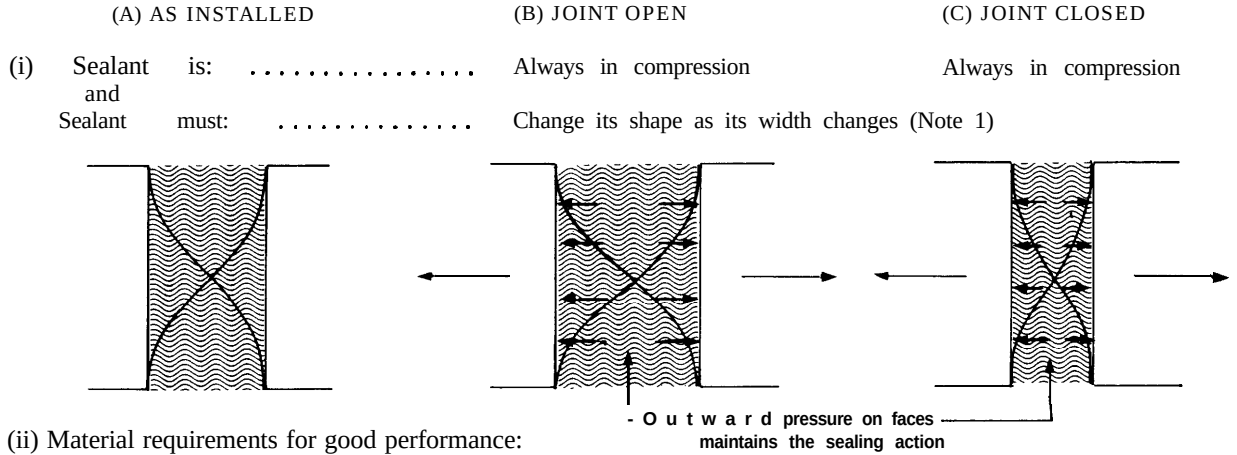
These considerations are discussed in detail in Chapter 4.

2.7-Shape factor in field-molded sealants

Field-molded sealants should be 100 percent solids (or semi-solids) at service temperatures and as shown in Fig. 2, they alter their shape but not their volume as the joint opens and closes. These strains in the sealant and hence the adhesive and cohesive stresses developed are a critical function of the shape of the sealant. For a given sealant then, its elastic

The behavior of these preformed sealants depends on a combination of their elastic and plastic properties acting under sustained compression.

① COMPRESSION SEALS AND GASKETS



(ii) Material requirements for good performance:

- (A)
- (a) Good contact (bond not needed)
 - (b) Correct size
 - (c) Suitable configuration

- (B)
- (d) Rubber-like properties

- (C)
- (e) Low compression set
 - (f) Webs should not weld
 - (g) Should not extrude from the joint

Also required (see Section 3.1) (1) Impermeability (3) Recovery (7) Nonembrittlement (8) Not deteriorate

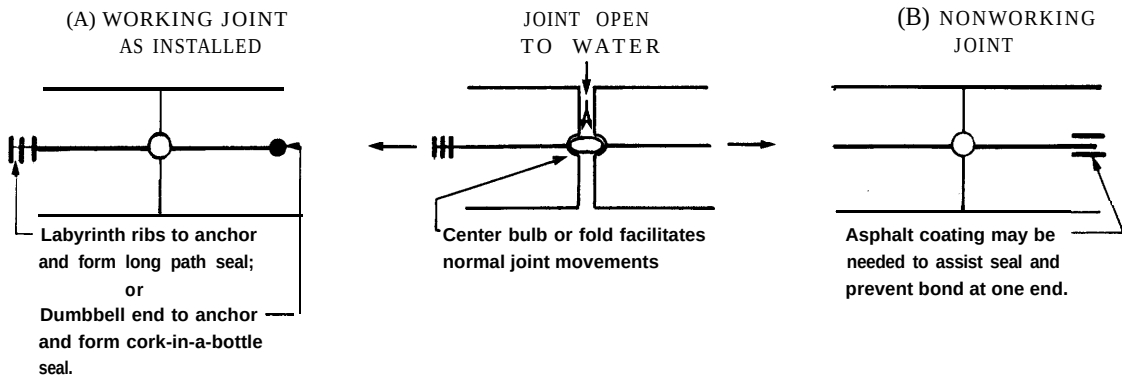
(iii) Deficiencies in (b) (d) (e) (f) predisposes to loss of contact pressure. See Fig. 3 ① for consequences

Note 1

Compression seals in working joints require to be compartmentalized or foldable to meet this criterion, gaskets in nonworking joints may not.

② WATERSTOPS

These seals are normally in tension during their working range.



(ii) Material requirements

- (A) (i) Flexible materials with properties similar to ① above
- (ii) Rigid flat plates also used where movement is comparatively small (otherwise sliding end or fold needed to permit movement). Must resist deformation due to fluid pressure. High durability since replacement not practical

- (B) (i) Rigid noncorrosive materials suitable, some ductility and flexibility may be desirable
- (ii) Flexible materials may be convenient but not essential

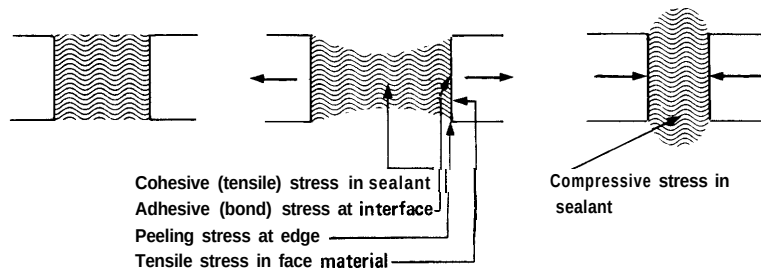
(iii) Deficiencies lead to failures shown in Fig. 3 ②

Fig. 1 -How preformed compression seals, gaskets, and waterstops work

The behavior of field-molded sealants in service depends upon a combination of their elastic and plastic properties. Elastomeric sealants should behave largely elastically to regain after deformation their original width and shape, that is full strain recovery (no permanent set) is desirable. However due to plastic behavior some set, flow, and stress relaxation occurs. The extent of its effect depends on the properties of the particular materials used and conditions such as temperature, repetition and rapidity of cycles of stress reversal and duration of deformation at constant strain. Largely plastic behavior, that is, returns to original shape by flow, is only acceptable for sealants used in joints with small and relatively slow movements.

① IN BUTT JOINTS

- | | (A) AS INSTALLED | (B) JOINT OPEN | (C) JOINT CLOSED |
|-----------------|------------------|---|------------------|
| (i) Sealant is: | | Sometimes in tension and sometimes in compression | |
| and | | | |
| Sealant should: | | Change its shape without changing its volume | |



- (ii) Material requirements for good performance:

- | | | |
|--------------------------|--|--|
| (A) | (B) | (C) |
| (a) Ease of installation | (e) High ultimate strength in rubberlike materials | (g) Resistance to flow and stress relaxation |
| (b) Good bond to faces | (f) Low elastic modulus in rubberlike materials | (h) Low compression set |
| (c) Homogeneity | (g) Resistance to flow and stress relaxation | |
| (d) Low shrinkage | | |

Also required (see [Section 3.1](#)) (1) Impermeability (3) Recovery (6) Resist flow (7) Not harden (8) Not deteriorate

- (iii) Deficiencies in
- | | |
|---|-------------------------------|
| (b) (c) (f) predispose towards adhesion failure | } See Fig. 4 for consequences |
| (c) (d) (e) predispose towards cohesive failure | |
| (h) (3) (6) predispose towards permanent deformation | |
| (g) (3) (6) predispose towards flow and stress relaxation | |
| (a) (7) (8) accelerate failures due to above causes | |

② IN LAP JOINTS

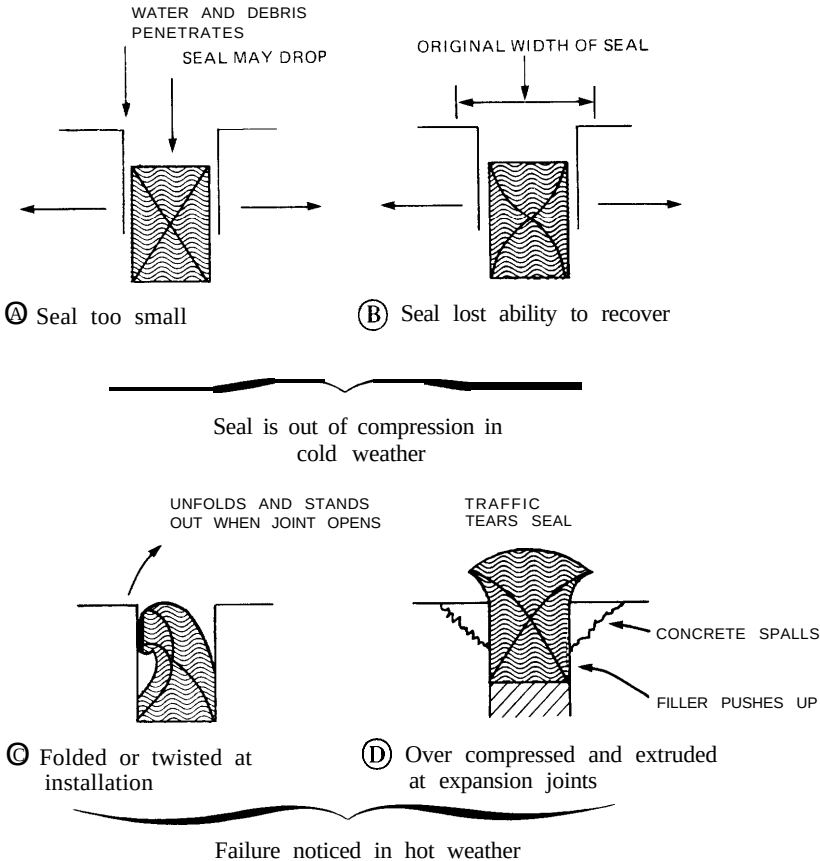
- | | (A) AS INSTALLED | (B) JOINT OPEN | (C) JOINT CLOSED |
|-----------------|------------------|-------------------------------------|-------------------------------------|
| (i) Sealant is: | | Always in shear ^(Note 1) | Always in shear ^(Note 1) |
-

- (ii) Material Requirements: These are generally similar to those above for butt joints. Same materials used (see [Chapter 3](#)) with thickness of sealant (distance between the overlapping faces) equal to 2 times the deformation of sealant in shear (which is the joint movement) depending on installation temperature (See [Fig. 5](#)).

Note 1: If, as lap joint opens or closes, units move closer together or farther apart in plane at right angles to main movement then compression or tension of the sealant will also occur. This combination of movements is common in many applications to buildings (see [Fig. 8](#)). Where both types of movement are expected, the combined movement should be considered to determine the thickness of sealant required in the joint design.

Fig. 2-How field-molded sealants work

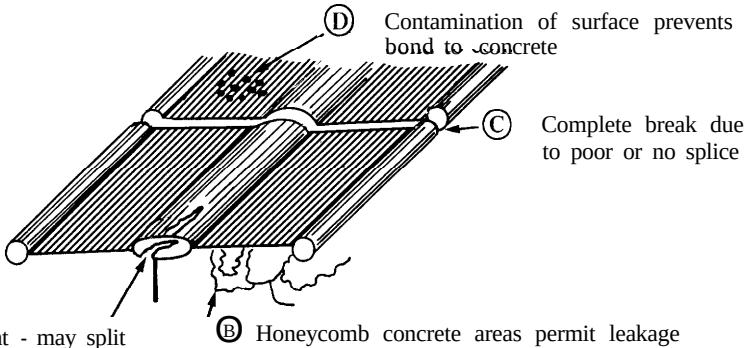
① Compression Seal Defects:



Improve Performance by:

- ③ (i) Use wider seal
 - (ii) Form or saw cut joint with shoulder support seal
 - (iii) Avoid stretching during installation
- ④
- ⑤ Install seal straight, lubricate joint faces and also to prevent breaks avoid stretching
- ⑥
- Usually occurs in pavements with mixed system of expansion-contraction joints, avoid this design
 - (ii) Form or saw groove wider
 - (iii) Leave air gap on top of filler

② Waterstop Defects:



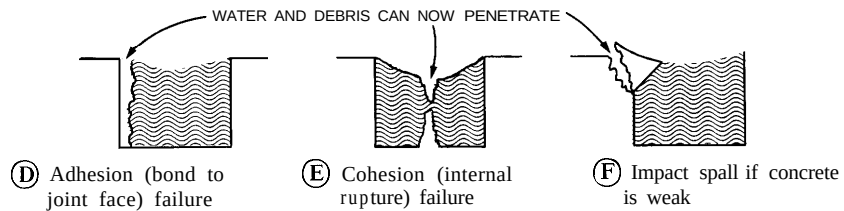
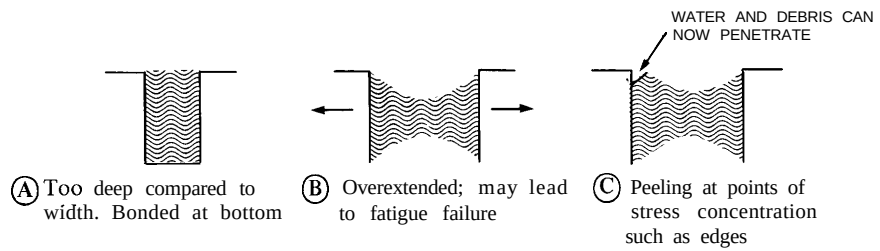
Improve Performance by:

- ③ (i) Selecting size suitable for joint movement
 - (ii) Avoid rigid anchored flat types
- ④ ⑤ ⑥
- (i) Proper installation and concreting practices
 - (ii) Since replacement is usually not possible try grouting or secondary sealant as remedy

Fig. 3 -Defects in preformed sealants

① Defects
Mainly
Associated with
Elastic
Behavior

Improve
Performance
by →



(i) (A)(B)(C) -Better shape factor to reduce strains to those sealant can withstand

(ii) Use of bond breaker and/or backup materials

(iii) Closer joint spacings to reduce individual movements

(iv) Select better sealant

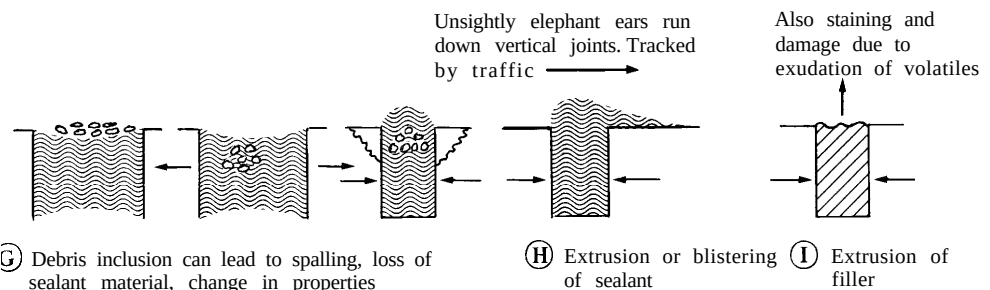
(v) (D) Clean faces and prime

(vi) (F) Saw rather than form armor edges

(vii) Improvements (i) to (vi) will greatly extend life of sealant. Eventual failure must be expected due to combinations of (B) (C) (D) (E), viscous flow, stress relaxation, permanent set etc., with repetitive cycles of stress reversals (See below)

② Defects
Mainly
Associated with
Non Elastic
Behavior

Improve
Performance
by →



(G)

(i) Select sealant that will resist intrusion

(ii) Routine cleanup of debris

(iii) Indentation by spiked heels, etc. requires (i)

(H) and (I)

(i) Use better shape factor

(ii) Closer joint spacings

(iii) Avoid mixed expansion contraction joint pavement designs so as to equalize movement

(iv) Avoid trapping air and moisture at installation

(v) Select better sealant and more compressible filler and do not overfill joints or set filler too high

③ Defects
Mainly
Associated with
Flow and Stress
Relaxation



(J) (i) sags or (ii) humps after extension or (iii) necks after compression as direction of movement reverses

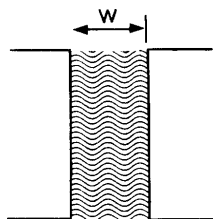
Little improvement possible if 'best' sealant is being used. Support may help somewhat.

Fig. 4 -Defects in field-molded sealants

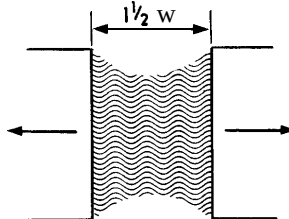
Hypothetical cases showing the effect of installation temperatures in relation to the range of service temperatures, assuming the joint width at mean temperature equals the total joint movement between fully open and fully closed positions. (for simplicity of analysis only temperature effects shown)

① SEALANT INSTALLED AT MEAN TEMPERATURE

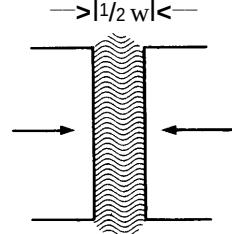
(A) INSTALLATION AT MEAN TEMPERATURES 55 F (13 C)



(B) JOINT OPEN AT -20 F (-29 C)



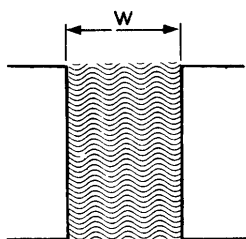
(C) JOINT CLOSED AT 130 F (54 C)



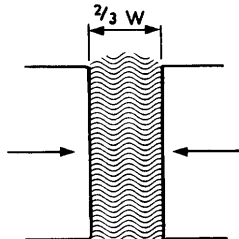
Sealant must extend or compress by 50 percent in service.

② SEALANT INSTALLED AT LOW TEMPERATURE

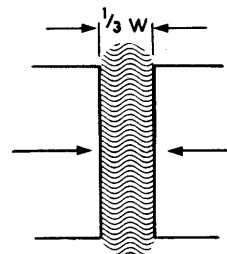
(A) INSTALLATION AT MINIMUM TEMPERATURES -20 F (-29 C)



(B) JOINT HALF CLOSED AT 55 F (13 C)



(C) JOINT CLOSED AT 130 F (54 C)

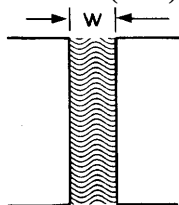


Sealant must compress by 66.66 percent in service.

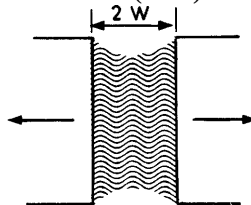
Probability of Permanent Deformation or Extrusion. 50 percent more sealant needed.

③ SEALANT INSTALLED AT HIGH TEMPERATURE

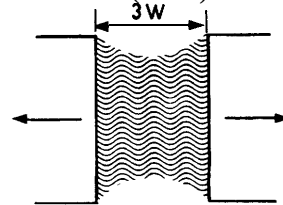
(A) INSTALLATION AT MAXIMUM TEMPERATURE 130 F (54 C)



(B) JOINT HALF OPEN AT 55 F (13 C)



(C) JOINT OPEN AT -20 F (-29 C)



Sealant must extend by 200 percent in service.

Adhesion, cohesion, or peeling failure certain.

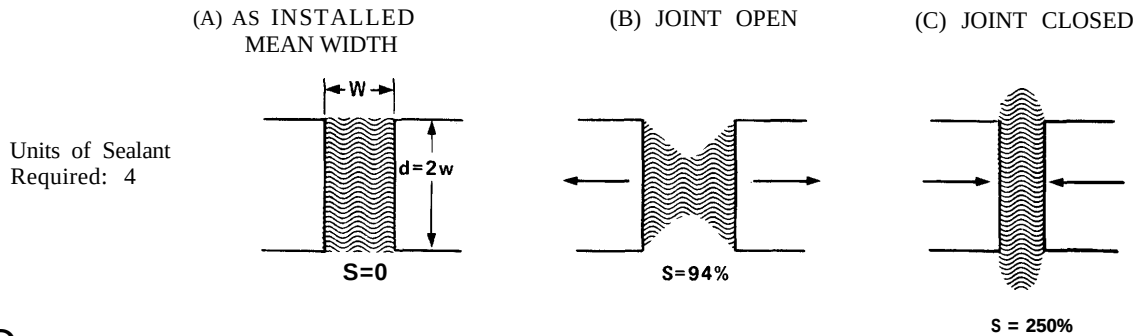
CONCLUSION: The closer the installation temperature is to the mean annual temperature the less will be the strain in the sealant in service and the better it will perform in butt joints. Taking into account practical considerations (see Chapter 4 and 6) an installation temperature range of from 40 to 90 F (4 to 32 C) is acceptable for most applications.

- Note: (i) Though not illustrated similar considerations govern the selection of the size of compression seals (see Section 4.5). Failure in case (3) above would however be by loss of contact with joint faces when seal passes out of compression.
- (ii) Maximum deformation of a sealant in lap joints is also governed by installation temperature. Sealant thickness not less than joint movement acceptable for all temperatures (see Fig. 2.2) may be reduced to $\frac{1}{2}$ provided installation temperature is between 40 and 90 F (4 and 32 C) (movement approximately $\frac{1}{2}$ each way).

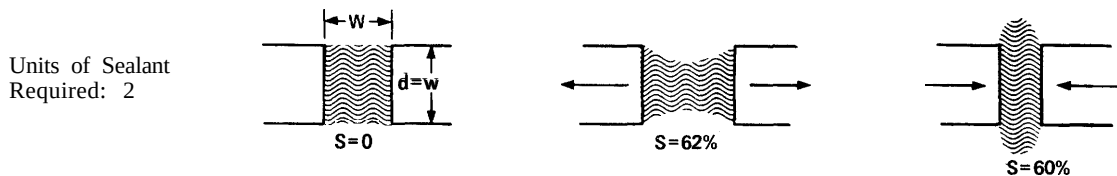
Cases showing the effect of shape on the maximum strains 'S' which occur on the parabolic exposed surface of elastomeric sealants. Sealant assumed to be installed at mean joint width so that $\frac{1}{2}$ change of width of sealant will be extension and $\frac{1}{2}$ compression.

BUTT JOINTS

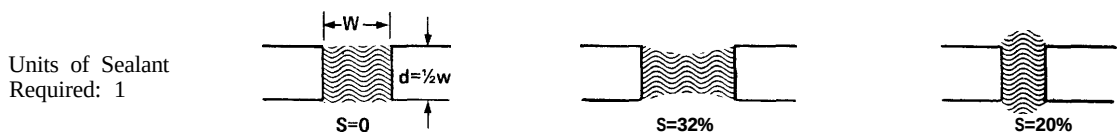
① JOINT DEPTH TO WIDTH RATIO 2: 1



② JOINT DEPTH TO WIDTH RATIO 1: 1

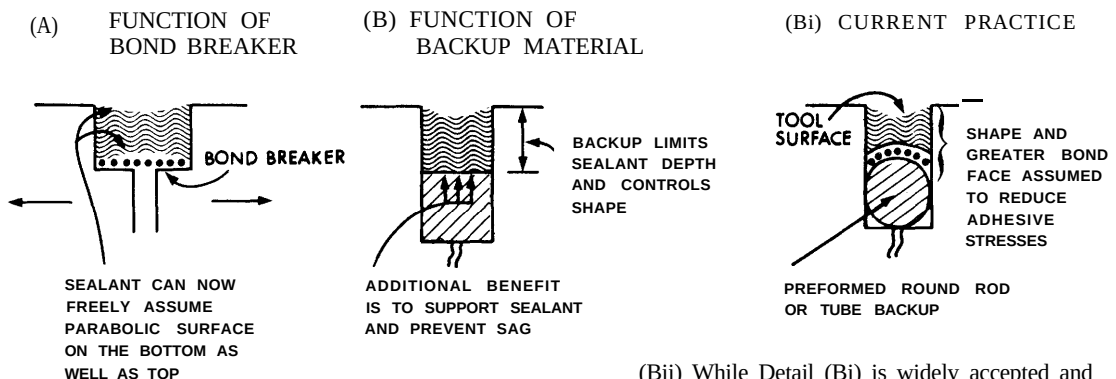


③ JOINT DEPTH TO WIDTH RATIO 1: 2



CONCLUSION: Increasing the width and reducing the depth generally reduces strains and hence improves performance of field molded sealants. At the same time less sealant is required. Shape Factor is less important in mastic sealants since plastic not elastic behavior dominates.

- ④ **PURPOSE OF BOND BREAKER AND BACK UP:** In joints open on one face only the back face of the sealant must not adhere to the bottom of the sealant reservoir so that the sealant is free to assume the desired shape. See (A) below. Control of depth of sealant is achieved as shown in (B) where the joint is formed or sawn initially deeper than the required depth to width ratio. (Bi) and (Bii) present cases as to desirable shape of backup.



(Bii) While Detail (Bi) is widely accepted and used, some recent research suggests (B) may be better since, if backup material presents flat face to sealant, peeling stresses at corners are reduced.

Fig. 6-Shape factor and strains in field-molded sealants

extensibility is a function of the shape of the mold in which it was installed as well as the physical properties of the material. A mathematical analysis of sealant deformation was made by Tons,⁴ whose laboratory measurements showed that the exposed surfaces of an elastically deformed sealant assume a parabolic shape until close to rupture. Tons concluded that total extensibility is increased directly with width and inversely with the depth of the sealant in the joint. From Tons's data and that of Schutz,⁵ Fig. 6 (1A, B, C, 2A, B, C, 3A, B, C) has been prepared to illustrate the critical importance (and economy) of using a good shape factor especially with thermosetting, chemically curing field-molded sealants. Shape factor pertains to the ratio between the width of a sealant and its thickness (depth) determined by experience and lab tests.

It must be remembered that while selections of shape factor are essentially based on accommodating cohesive stresses in the sealant, at the time of placement an adequate area must be provided at the joint face to accommodate adhesive (bond) stresses. For this reason, experience has indicated a preference in certain applications, such as in concrete pavements, for a minimum 3:2 (depth to width) shape factor rather than the theoretically more desirable ratio (shown in Fig. 6) of 1:1 or 1:2 in order to achieve a better service performance.

2.8-Function of bond breakers and backup materials

Bond breakers and backup materials are used, as illustrated in Fig. 6 (4A, B), to achieve the desired shape factor in field-molded sealants. The principal material requirement for a bond breaker is that it should not adhere to the sealant. Important secondary benefits of a backup material are that it supports the sealant and helps resist indentation, sag and allows a sealant to take advantage of maximum extension. These may often be important considerations when selecting the appropriate type and shape of preformed backup material. The backup material must also be compressible without extruding the sealant and must recover to maintain contact with the joint faces when the joint is open.

2.9-Function of fillers in expansion joints

Fillers are used in expansion joints to assist in making the joint and to provide room for the inward movement of the abutting concrete units as they expand. Additionally they may be required to provide support for the sealant or limit its depth in the same manner that backup materials do. These requirements are usually met by preformed materials that can be compressed without significant extrusion and preferably recover their original width when compression ceases. Stiffness to maintain alignment during concrete placement and resistance to deterioration due to moisture and other service conditions are also usually required.

2.10-Function of primers

Laboratory and field experience indicates that priming joint faces is essential for certain field-molded sealants and can generally improve their bond strength and hence extensibility, especially at low temperatures. Depending on the sealant and condition of the sealant-to-joint interface, the improvement in adhesion may result from one or more of the following: sealing and penetration of the concrete pores, pre-coating of the concrete pores, pre-coating of the dust parti-

cles, reduction in bubble formation, and reduction in the absorption of oils by the concrete.

CHAPTER 3-SEALANT MATERIALS

3.1-General

This chapter deals with the functional properties of sealing and accessory materials. Because of their physical limitations many materials only perform well in joints of small initial width and subsequent movement. The configuration of the joint, the process by which it is constructed (formed) and access for installation of the sealant also impose restrictions on the types of material that may be suitable for a particular application.

In service, environmental conditions often dictate additional performance requirements beyond those needed to accommodate movements alone.

Selection of the most appropriate materials for a particular application is not a simple matter in view of all the variables involved. Once an understanding is gained of the basic properties of materials required, then available materials can be classified and related to their suitability in various types of joints. This information is conveniently displayed in a series of tables and is cross referenced in later figures which illustrate the details of various joint applications in concrete structures.

This chapter discusses field molded sealing materials used where one surface of the finished joint is open to permit the sealing operation. Sealants used for these applications are listed in Table 1. The joint design for an expansion (isolation) joint may consist of a filler strip below the area where the sealant will be placed, bond breaker material to separate the sealant from an adhering substrate, and backup materials to support the material from sagging. These appurtenant materials are listed in Table 2. Preformed materials used in joints open on at least one surface, materials used as water stops and gaskets are listed in Table 3.

Table 4 shows some of the current uses to which the various sealants are put, and consideration of storage and handling for installation. In cross-referencing types of materials the Roman numeral system is used in Tables 1 and 4 and in Fig. 7 to 12. Individual field-molded sealant materials are lettered A, B, C, and so on, as in Table 1. Individual preformed sealant materials are identified by numbers given in Table 3.

Appendix C lists various specifications and sources of current specifications.

3.2-Required properties of joint sealants

For satisfactory performance a sealant must:

1. Be an impermeable material.
2. Deform to accommodate the movement and rate of movement occurring at the joint.
3. Sufficiently retain its original properties and shape if subjected to cyclical deformations.
4. Adhere to concrete. This means that for all sealants; except those preformed sealants that exert a force against the concrete surfaces or are mechanically interlocked with an anchorage, the sealant must bond to the concrete surfaces and not fail in adhesion (lose its bond to the concrete) nor peel at corners or other local areas of high stress (see Fig. 4).

TABLE 1-MATERIALS USED FOR JOINT SEALING

GROUP		FIELD-MOLDED				PREFORMED
TYPE	I MASTIC	THERMOPLASTICS		THERMOSETTING		VI COMPRESSION SEAL
		II HOT APPLIED	III COLD APPLIED	IV CHEMICALLY CURING	V SOLVENT RELEASE	
Composition	(A) Drying Oils (B) Non-drying Oils (C) Low Melt. Point Asphalt (D) Polybutenes (E) Polyisobutylenes or combination of D & E All used with fillers, all contain 100% solids, except D & E which may contain solvent.	(F) Asphalts (G) Rubber Asphalts (H) Pitches (I) Coal Tars (J) Rubber Coal Tars All contain 100% solids (W) Hot applied PVC coal tar	(K) Rubber Asphalts (L) Vinyls (M) Acrylics (K) Contains 70-80% solids (L) (M) Contain 75-90% solids All contain solvent, (K) may be an emulsion (60-70% solids). (X) Modified Butyl Rubber	(N) Polysulfide (O) Polysulfide Coal Tar (P) Polyurethane (Q) Polyurethane Coal Tar (R) Silicones (S) Epoxy (N),(R) contain 95-100% solids (O),(Q),(S) contain 90-100% solids (P) contains 75-100% solids (N),(P),(R) may be either one or two component system (O),(Q), (S) two component system.	(T) Neoprene (U) Butadiene Styrene (V) Chlorosulfonated Polyethylene (T) (V) contain 80-90% solids (U) contains 85-90% solids (R) Silicones	(3) Neoprene rubber
Colours	(A) (B) Varied (C) Black only (D) (E) Limited	Black only	(K) Black only (L) (M) Varied	(N) (R) (S) Varied (O) (P) Limited (Q) Black only	(T) Limited (V) Varied	Black. Exposed surfaces may be treated to give varied colours
Setting Or Curing	Non-curing, remains viscous, A and B form skin on exposed surface.	Non-curing, sets upon cooling. Softens on warming, hardens on cooling (W) Resilient	Non-curing, sets on release of solvent or evaporation of water. (M) remains soft except for surface skin.	Two component system-catalyst. One component moisture pickup from the air	Release of solvent	
Aging and Weathering Resistance	Low	Moderate (W) High resistance to weather	Moderate	High	High	High
Increase in Hardness in Relation to (1) Age	High	High to Moderate (W) No hardness	High	(S) High (N) (O) (P) (Q) (R) Moderate	High	Low
or (2) Low temp	High	High to Moderate (W) No hardness	High	(S) (N) (O) (P) (Q) (R) Low	High	Low
Recovery	Low	Moderate (W) High	Low	(N) (O) Moderate (P) (Q) (R) High (S) Low	Low	High
Resistance to Wear	Low	Moderate	Moderate	(P) (O) (R) (S) (N) (O)	Moderate	High
Resistance to Identification and Intrusion of Solids	Low	Low at High temperatures (W) High	Low at high temperatures	High	Low	High
Shrinkage after Installation	High	Varies (W) None	High	Low	High	None
Resistance to Chemicals	High except to solvents and fuels	(F) (G) High except to solvents and fuels (H) (I) (J) High and fuel resistant (W) High	(K) High except to solvents and fuels (L) (M) High except to alkalis and oxidizing acids	(N) (P) Low to solvents, fuels, oxidizing acids (O) (Q) Low to solvents but moderate fuel resistance (R) Low to alkalis (S) High	Low to solvents, fuels and oxidizing acids	High
Modulus at 100% Elongation	Not applicable	Low	Low	(R) (O) (P) (Q) Low (R) High and Low (S) Not applicable	Moderate	
Allowable Extension and Compression	±3%	+ 5% (W) ± 25% extension	±7%	±25% except (S) less + 100% some (R) 50%	±7%	Must be compressed at all times to 45-85% of its original width
Other Properties	(A) (B) (D) (E) Non-staining (D) (E) Pick up dirt, use in concealed location only.	Due to softening in hot weather usable only in horizontal joints (W) No flow at elevated temperatures	(K) Usable in inclined joints	(N) (P) (R) (S) Non-staining	(U) (V) Non-staining (V) Good vapour and dust sealer	
Unit first cost	(A) (B) (C) very low (D) (E) Low	(F) (G) (H) (I) (J) Very low (W) Medium	(K) Very low (L) Low (M) High	(O) (Q) (R) High (N) (P) (R) (S) Very High	(T) (U) (V) Low	(3) High

5. Not internally rupture or pull apart within itself (that is, fail in cohesion) (see Fig. 4).

6. Resist flow due to gravity (or fluid pressure) or unacceptable softening at higher service temperatures.

7. Not harden or become unacceptably brittle at lower service temperatures.

8. Not be adversely affected by aging, weathering or other service factors for a reasonable service life under the range of temperatures and other environmental conditions that occur (see Fig. 7 to 12).

In addition, depending on the specific environmental conditions, the sealant may be required to resist one or more of the fol-

**TABLE 2-PREFORMED MATERIALS USED FOR FILLERS AND AS BACKUP WITH
FIELD MOLDED SEALANTS**

COMPOSITION AND TYPE	USES AND GOVERNING PROPERTIES	INSTALLATION
(1) Natural rubber (a) Sponge (b) Solid	Expansion joint filler. Readily compressible and good recovery. Closed cell. Non-absorptive. Solid rubber may function as filler but primarily intend as gasket, see Table 3(8).	High pliability may cause installation problems. Weight of plastic concrete may precompress it. In construction joints attach to first placement with adhesive.
(12) Neoprene or Butyl Sponge tubes	Backup Where resilience required in large joints. Check for compatibility with sealant as to staining.	Compressed into joint with hand tools.
(13) Neoprene or Butyl Sponge rods	Backup Used in narrower joints, e.g. contraction joints in canal linings and coverslabs and pavements. Check for compatibility with sealant as to staining.	Compressed into joint with hand tools or roller.
(14) Expanded polyethylene polyurethane and polyvinyl chloride polypropylene flexible foams	(a) Expansion joint fillers. Readily compressible, good recovery, Non-absorptive. (b) Backup Compatible with most sealants	Must be rigidly supported for full length during concreting. Compressed into joint with hand tools.
(15) Expanded polyethylene, polyurethane and polystyrene rigid foams	Expansion joint filler. Useful to form a gap but after significant compression will not recover.	Support in place during concreting. In construction joints attach to first placement. Sometimes removed after concreting where no longer needed.
(16) Bituminous or Resin Impregnated corkboard	Expansion joint filler. Readily compressible and resilient. Not compatible and must be isolated from most non-asphaltic sealants.	Support in place during concreting, or attach to preceding placement. Boards easily damaged by careless handling.
(17) Bentonite or Dehydrated Cork	Filler with self-sealing properties. Absorption of water after installation causes material to swell. Cork can be compressed. Bentonite incompressible.	Cork available in moisture-proof liners that require removal before installation. Bentonite in powder form, loose or within cardboard liners.
(18) Wood Cedar, Redwood, Pine, Chipboard, Untreated Fibreboard	Expansion joint filler, has been widely used in the past. Swells when water is absorbed. Not as compressible as other fillers and less recovery. Natural woods should be knot-free.	Rigid and easily held in alignment during concreting.
(19) Bituminous impregnated fiberboard	Expansion joint filler. Widely used. Resilient cane fibre used. Has moderate recovery after compression. Should not be compressed more than 50 percent or bitumen extruded which may damage sealant.	Reasonably rigid to hold alignment during concreting or placed against preceding placement.
(20) Metal or Plastic	(a) Expansion joint filler. Hollow compressible thin gauge box. Used only in special applications. (b) Backup, Foil, inert to sealants, but shape irregular.	Installed as for wood or fibreboard materials. Crumple and place in joint.
(21) Glass Fibre, Mineral wool	(a) Expansion joint filler. Made in board form by impregnating with bitumen or resins. Easily compressed. (b) Backup. Inert without impregnation so as not to damage sealant.	Installed as for wood or fibreboard materials. In mat form or packed loose material or yarn.
(22) Oakum, Jute, Manila yarn and rope, and Piping Upholstery cord	The traditional material for packing joints before installing sealant. Where used as backup should be untreated with oils, etc.	Packed in joint to required depth
(23) Portland Cement Grout or Mortar	Used at joints in precast units and pipes to fill the remaining gap when no movement is expected and sometimes behind waterstops.	Bed (mortar) Inject (grout)

