Genesis of Modern Sealant Technology

By Raymond J. Schutz

Synopsis: Joints in structures existed since men first constructed a waddle hut or a bark canoe. These joints were subject to movement then as now. Early structures shedded rain at the joints due to overlapping of small elements such as thatch, slate, clapboard or board and batten. Where overlapping was impractical, (such as in a log hut) early builders used sealants of mud, moss, shredded bark, or pine pitch. As man became more skilled, he developed bituminious-based sealants and sealants based on natural drying oils.

As buildings became more sophisticated, elements became larger and movement at the joints increased. Field molded elastomeric sealants were developed with performance far exceeding sealants based on natural materials. These were welcomed by the industry as the final solution, however, despite their excellent properties, field performance was quite often disappointing.

This paper covers the development of sealant technology based on the study of joint movement and geometry. Understanding of the high strains which can occur in a sealant has resulted in better design and limits for field-molded sealants and has led to the development of compression seals, mechanically locked and modular preformed sealants for joints which are subject to extreme movement.

Keywords: bitumens; bridges (structures); concrete pavements; history; joint sealers; joints (junctions); mechanical properties; neoprene; plastics, polymers and resins; structural design; structures.

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INTRODUCTION

Joints in structures have existed since man first constructed a waddle hut or a bark canoe. These joints were subject to movement then as now. Early above-grade structures shedded rain and weather at the joints due to overlapping of small elements such as thatch, slate, clapboard or board and batten. Where overlapping was impractical (log huts) early builders used sealants based on mud, moss and shredded bark or pine pitch. The first specification the author could find on the use of sealants was issued for the construction of a large seagoing vessel to transport animals. This specification can be found in the Old Testament and was issued by God to Noah (Genesis 6:14, "Make thee an ark of gopher wood; rooms shall thou make in the ark and shall pitch it within and without with pitch.") This vessel was apparently used for only one voyage and was abandoned on Mt. Ararat in Turkey.

Ancient contractors also used sealants on their own without the benefit of specifications. There is also a reference in the Old Testament to the use of slime and pitch-based sealants being used in the construction of a basket made for Moses by his mother (Exodus 2:3, "She took for him an ark of bulrushes, and daubed it with slime and with pitch "). The ancient egyptian temple at Karnak was reported to have used sealants referenced as bituminous-based. Early roads were unpaved or paved with stone-sets or what is known as Belgium Block. The joint spacing in this system was so close that sealants were not required.

Oakum and pitch-saturated rope became the first preformed sealants. As man became more skilled he developed bituminous-based sealants and sealants based on natural drying oils. Drying oil with fillers are used to this day and do an acceptable job within their limitations. The life expectancy and movement capabilities of sealants based on drying oils are not as great as the synthetic elastomers, but for small joints subject to very small movements (less than 5%) a maintenance-free life expectancy of 5 to 10 years may be anticipated. (1,2).

New elastomeric sealants such as those based on polysulfides and polyurethane polymers were developed and when used in properly designed joints have a life expectancy of 20 years. (3)

PAVEMENTS AND BRIDGES

Sealants for pavements and bridges present a different problem than structures since spacing and joints on a bridge deck are governed by necessity. Other considerations are: the bridge has to span a river, valley or other obstruction; the distance between joints may be extremely large; the heat sink of mother earth is not present on a bridge deck to minimize the rate and extent of movement; there is no heated interior to minimize temperature extremes as in a building and deck temperatures will closely follow descending ambient temperatures and the deck will also be heated above ambient temperatures by solar energy.

Pavement joints may be spaced as desired but sawed joints present a very poor shape factor for sealing and joints (both dowel and aggregate interlock) tend to freeze adding movement to the working joints. Incompressibles such as stone, sand and other debris may also prevent movement in a joint causing growth of the pavement on temperature rise and transfer of the movement to the working joints. These frozen joints may actually cause the pavement to buckle and heave (blowout) or actually push bridges off their supports!

FAILURES OF SEALANTS

The American Concrete Institute's Guide to Joint Sealants for Concrete Sturctures lists over 35 chemical types of field-molded sealants both thermoplastic and thermoset. All can perform satisfactorily if installed in a joint with movement and design within their capabilities. However, even using these excellent materials failures can occur in sealant systems. These failures led to a study as to why a given sealant will perform in one joint and not in another.

JOINT DESIGN AND FIELD-MOLDED SEALANTS

Field-molded sealants are solids (elastomers) or liquids rendered immobile by fillers and fibers (mastics). Their shape can be altered by movement of the joint slot but their volume will remain constant, for all practical purposes. Assuming there is no adhesive failure, the sealant must change shape to accommodate joint movement. Figure 1 illustrates this change in shape which will occur on extension of joint slots (Figure 2) on contraction of the joint slot. Note the strain on the outer fiber of the joint will be greater than the strain on the neutral axis and the strain on the outer fiber will vary with the ratio of the depth-to-width of the joint slot. It is this strain on the outer fiber or the shape factor which will govern the performance of a given sealant--not the extension or contraction of the joint slot as such. The effect of movement on the strain of the outer fiber of the sealant for various shape factors is shown in Figure 3. (4,5) It is obvious from this mathematical relationship that a flat shape factor is the most efficient for any field-molded sealant. This mathematical relationship holds true only if the sealant is free to change shape ("neck" down and up) on both top and bottom. If the sealant adheres to the bottom of the joint slot or back up material, all movement will have to take place on the top fiber and the bottom fiber will not be free to move resulting in restricted movement and failure as illustrated in Figure 4.

This led designers to try joints with very flat shape factors, depth-to-width ratios of less than one. In many instances, these flat shape factors have proven quite successful. Figures 5 and 6 illustrate two such designs. Note, however, that such flat designs are quite vulnerable to mechanical damage, the depth being limited by sufficient bond area of the sealant to the sides of the joint slot, usually a quarter-inch minimum. The joints shown in Figure 6 have sufficient bond area but the joint is very vulnerable to mechanical damage and presents a very poor aesthetic and architectural effect.

Where movement is such that a very wide joint is required for proper design, the joint must be protected from mechanical damage. Figure 5 illustrates a properly designed joint from a theoretical standpoint. The sealant did withstand the anticipated movement, in this instance a bridge deck, but being very wide it was quickly destroyed by traffic and debris. Where design dictates a very wide shape factor, field molded sealants become too vulnerable to vehicular traffic, ladies spike heels and other mechanical abuse on horizontal surfaces and on vertical joints in buildings they are unsightly and become targets for the prying of little fingers. In all cases, wide joints are costly and very often exhibit poor performance. The limitations imposed on field-molded sealants by the mathematics of shape factor led to the study and use of premolded sealants.

PREMOLDED SEALANTS

The study and eventual understanding of the importance of shape factor on the performance of field molded sealants led the construction industry to develop premolded sealants, both bonded and compression seals. An early design of a bonded premolded sealant is illustrated in Figure 7. A compressed neoprene tube is bonded to precast panels with an elastomeric sealant. On expansion of the joint slot, the tube will tend to assume its original circular cross section; on contraction of the slot, movement will compress the seal to a more elliptical cross section.

Another early design is the bellows joint formed by bonding or mechanically fastening a draped sheet of neoprene or butal rubber as shown in Figure 8 . Also, an upward drape can be used and is common in roofing joints as shown in Figure 9. On horizontal surfaces the downward draped bellows must be pitched to a drain. However, experience has shown that such a design collects debris and water may freeze in the drape causing failure or high maintenance costs.

The next step in the progress of premolded sealants was the compression seal. Such a seal when kept in continuous compression will provide a seal for the joint and will withstand the movement of the joint slot without the application of any strain in extension or compression of the sealant material. The sealant material, usually neoprene, will be subject to bending and not compression or extension. Shape factor no longer governs the design; a typical compression seal is shown in Figure 10. Compression seals have found a place not only in pavements but as building construction sealants between precast elements in both single and double-stage joints.

Compression seals perform adequately as long as the seal is under continuous compression. This presented a problem where movements were very large and the next logical step was the development of mechanically anchored single and multi-stage premolded sealants. By properly anchoring a series of compression seals mechanically, a modular compression seal system can be developed to take any movement; movement in feet or meters can actually be accommodated as seen in Figure 11. (6)

Another variation of a premolded sealant is the tension compression seals, that is, seals which are mechanically anchored to both sides of the joint slot so designed that the sealant takes up movement in shear. Figure 12 shows the representative cross section of typical tension-compression seals. Again, this design has eliminated the constrictions of shape factors, but movement is limited to the capability of the elastemer in both shear and fatigue.

CONCLUSION

Sealant technology has progressed from the slime and pitch of the ancients to technology based on sound mathematics and chemical technology. Systems can be designed to economically seal joints with movement measured in feet or meters. There is a large choice of chemical types available in field-molded sealants, each with its own characteristics in regard to performance and economics.

Where movement or mechanical abuse is beyond the capabilities of field-molded sealants there are great varieties of excellent compression seals, tension-compression seals and modular-compression seals available to the designer. The ACI Guide to Joint Sealants for Concrete Structures covers almost all joint sealing situations and is an excellent reference and design aid.

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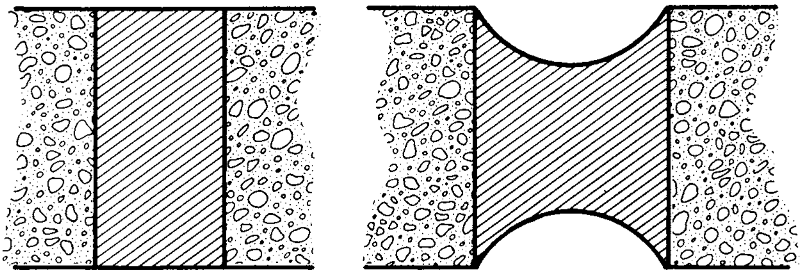
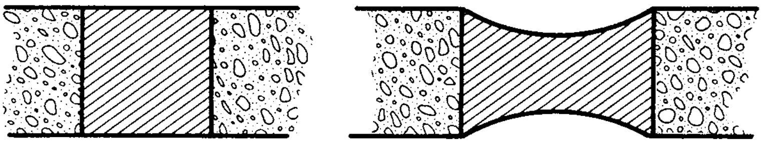
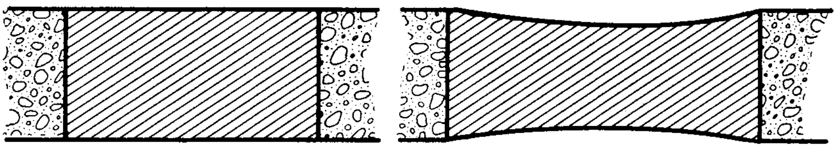


Strain on outer fiber, 94%
1 X 2 Shape factor



Strain on outer fiber, 62%
1 X 1 Shape factor



Strain on outer fiber, 32%
2 X 1 Shape factor

Fig. 1--Effect of shape factor on strain on the outer fiber of sealant for equal joint movement/extension

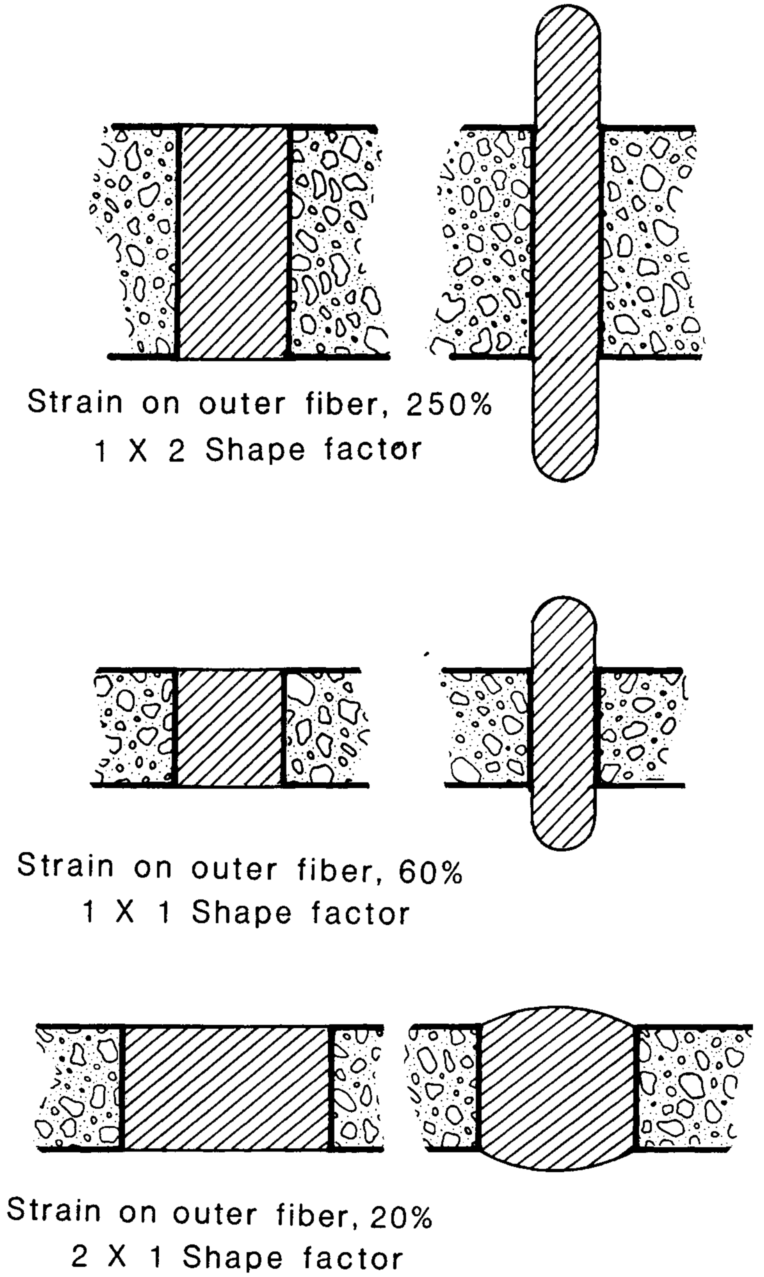


Fig. 2--Effect of shape factor on strain on the outer fiber of sealant for equal joint movement/compression

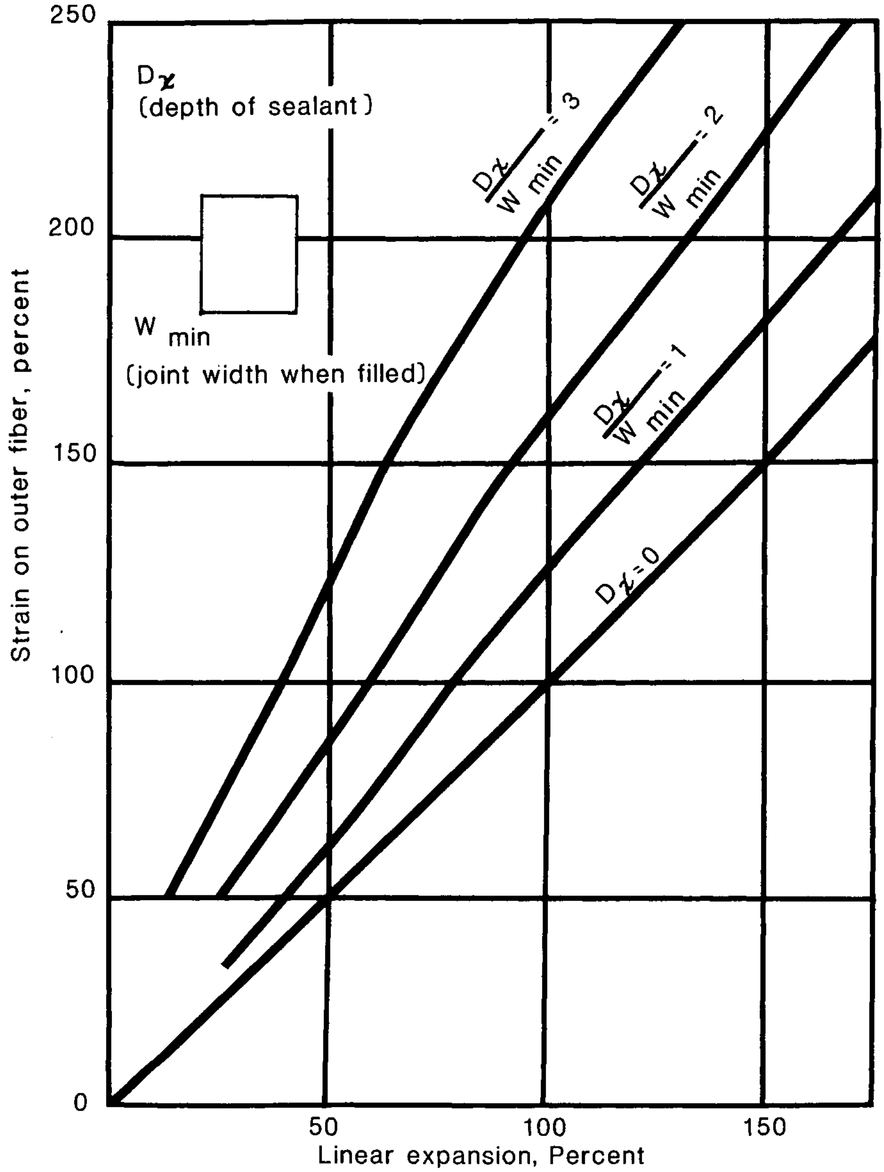


Fig. 3--Strain on outer fiber of a sealant plotted against percentage of linear expansion applicable to any joint and any sealant

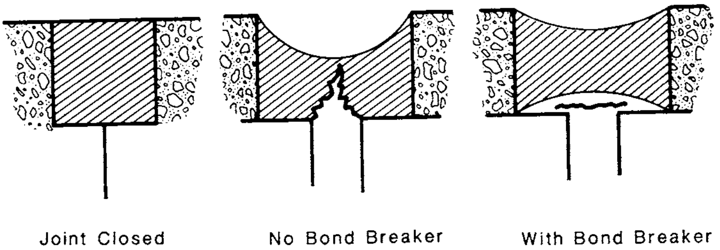
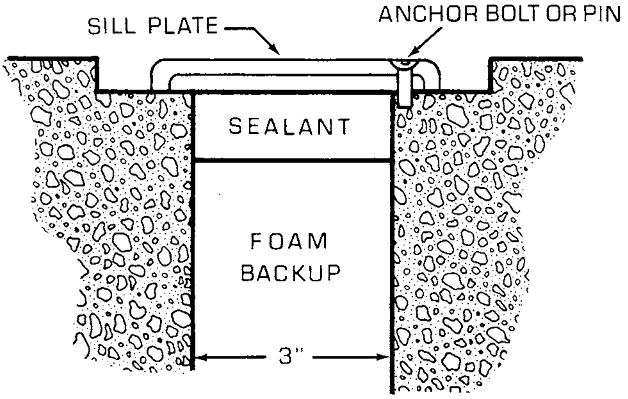


Fig. 4--Effect of bond breaker on sealant performance



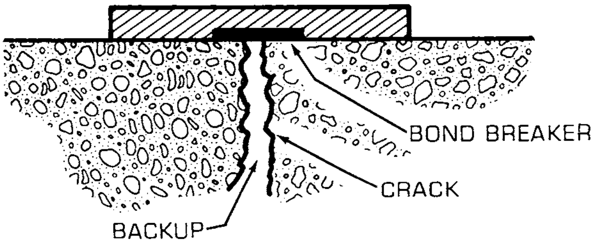


Fig. 5--A joint with a well-proportioned sealant, covered by protection

Fig. 6--Flat shape factor joints with adequate bond area