Effects of Specimen Length on Laboratory Behavior of Sealants

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To provide the maximum degree of predictability of a product, the laboratory testing environment should approach service conditions as closely as practicable. Current practice in the testing of sealants is to use a 2-in. long specimen. However, a sealant in use may be as long as 40 ft. Specimen lengths of 2, 4, and 6 in. are used to show variation in test results with length.

Assuming the sealant to be a perfectly elastic material, stresses in the sealant are computed mathematically. Experimental values of specimens with end neckdown are used. Values of modulus and ultimate strain are measured. A qualitative evaluation of the sealant stresses is shown by photoelastic pictures.

•THE PURPOSE of laboratory testing of any part or product is to predict its behavior in service. Literally millions of dollars have been spent in the effort to make the laboratory test simulate field conditions as closely as possible.

To some extent, this trend is also found in the sealants field. There are some fine environmental testing facilities which control the many parameters involved in sealant testing, such as temperature, humidity, and rate of extension. However, there is one aspect of sealant testing which remains somewhat unrealistic.

STATEMENT OF THE PROBLEM

An actual section of sealant in a pavement joint may have cross-section dimensions on the order of 1 by 1 in., but the sealant strip may extend across two or three lanes of traffic and be as long as 30 or 40 ft in a transverse joint. If the laboratory test is to predict the field behavior, the size and shape of the test specimen should conform as closely as practicable to the field conditions.

The current practice in the testing of sealants is to use a 2-in. long specimen. Much has been said about the shape factor and the neckdown of sealants under a tensile load. However, a short specimen of sealant material is a three-dimensional entity and when a specimen is extended in one direction, both of the other dimensions will change. The sealant specimen will neckdown in its longitudinal dimension, as well as in the vertical transverse direction. On the other hand, the sealant in the actual joint is a length dimension perhaps 400 times as large as the cross-section dimensions, so that the neckdown in this direction is virtually zero.

In the original derivation of the shape factor, Tons (1) assumed a constant volume sealant and also assumed no neckdown in the longitudinal dimension, so that all change in shape was in the vertical transverse direction. It is true, therefore, that the short, 2-in. specimen is not consistent with the basic conditions on which the shape factor derivation is based.

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THEORY

How long, then, should a sealant specimen be? This question may perhaps best be answered by examining the end points to determine the limits of the problem and then comparing the results of actual test specimens with these end points to determine a practical specimen size. The end points might be defined as follows: (a) a unit cube of material which, when extended in one direction is completely free to deform in its other two dimensions, and (b) a specimen with a square cross-section but an infinite length in its third dimension.

If the sealant is considered a perfectly elastic material, the internal work of deformation according to Treloar's (2) kinetic theory is expressed as:

$$W = 1/2\, G \left(\lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3 \right) \tag{1}$$

in which G is shear modulus, and λ is ratio of extended length to the original dimension, in each of three directions. The external work done by the applied forces is

$$dW = f_1\, d\lambda_1 + f_2\, d\lambda_2 + f_3\, d\lambda_3 \tag{2}$$

Differentiating the internal work expression and equating it to the external work expression yields a set of simultaneous equations:

$$\begin{aligned} \lambda_1 f_1 - \lambda_3 f_3 &= G\left(\lambda_1^2 - \lambda_3^2 \right) \\ \lambda_2 f_2 - \lambda_3 f_3 &= G\left(\lambda_2^2 - \lambda_3^2 \right) \end{aligned} \tag{3}$$

In the unit cube specimen, the only work done is in the tensile (λ_1) direction so that the external work expression reduces to

$$dW = f_1\, d\lambda_1 \tag{4}$$

In a unit section (or free body) cut from the infinite length specimen, there must exist a stress in the longitudinal (λ_3) direction to hold the dimension in this direction constant. The external work expression, therefore, contains both λ_1 and λ_3 terms.

In the unit cube specimen, since the sealant undergoes no change in volume, the following relationship must hold true:

$$\lambda_1\, \lambda_2\, \lambda_3 = 1 \tag{5}$$

Therefore, for this specimen under simple elongation, the extension ratios are $\lambda_1 = \lambda$, $\lambda_2 = 1/\sqrt{\lambda}$, and $\lambda_3 = 1/\sqrt{\lambda}$.

Since the only external force acting is in the tensile (λ_1) direction, the stress reduces to

$$f = \frac{dW}{d\lambda} = G\left(\lambda - \frac{1}{\lambda^2} \right) \tag{6}$$

Using for comparison an extension of 100 percent and a shear modulus of 10 psi, this stress becomes f = 10 (2 - 1/4) = 17.5 psi.

For the unit free body cut from the infinite length specimen, the simultaneous equations must be used. The extension ratios for this case are $\lambda_1 = \lambda$, $\lambda_2 = 1/\lambda$, and $\lambda_3 = 1$. The simultaneous equations reduce to:

$$
\begin{aligned}
2 f_1 - f_3 &= G(4 - 1) \\
- f_3 &= G(1/4 - 1)
\end{aligned}
\tag{7}
$$

so that $f_1 = 1.875$, G = 18.75 psi; and $f_3 = 0.75$, G = 7.5 psi. Combining these two values gives a principal stress in the sealant, f = 22.3 psi. This value is 21.5 percent higher than the unit cube specimen. It is important to note that the stress in the λ_1 direction varies by only about 6 percent.

With these two end points which are 21 percent apart as a basis for comparison, it is to be expected that the experimental results would fall within this range. The shorter specimens should approach the lower limit (17.5 psi) and the longer specimens should show a principal stress approaching the upper limit (22.3 psi).

EXPERIMENTAL WORK

The experimental work was performed with 2-, 4-, and 6-in. long specimens. Cross-sections dimensions of the specimens were 3/4 by 1 1/2 in. The material used was a gray, two-component pourable polysulfide sealant. The specimens were extended 100 percent and the neckdown in the longitudinal (λ_3) direction was measured with a micrometer depth gage. Transverse (λ_2) neckdown values were computed from the constant volume relationship. Table 1 includes both the experimental data and the solution of the equations for the values of stress in the specimen. Each value of experimental data represents the average of four specimens. The percent variation given is the variation from the upper limit which is considered to be the true value. The values indicate that the very short (2-in.) specimens give the same value, 17.5 psi, as the unrestrained cube. A quick extrapolation of the tabular results would indicate that a specimen 10 or 12 in. long would give results within 5 percent of the upper limit values. However, much of the testing equipment currently in use may not be able to handle such long specimens.

Figure 1 shows strain patterns on sealant specimens in 2-, 4-, and 6-in. lengths. Lines are scribed on the specimens at 1/4-in. spacing. In the 6-in. specimen the lines are curved for about 1 1/2 in. in from each end of the specimen. This leaves 50 percent of the specimen undisturbed by end effects. On the other hand, the curved lines on the 2-in. specimen indicate that this piece is dominated by the effect of the end neckdown.

TABLE 1

Specimen Length (in.)	Extension (%)	Longitudinal Neckdown (in.)	λ_1	λ_2	λ_3	f_1 (psi)	f_3 (psi)	Principal Stress (psi)	Variation (%)
2	100	0.29	2.0	0.714	0.7	17.4	0.3	17.5	21.5
4	100	0.30	2.0	0.588	0.85	18.3	4.4	19.2	13.9
6	100	0.32	2.0	0.555	0.90	18.4	5.55	19.9	10.5

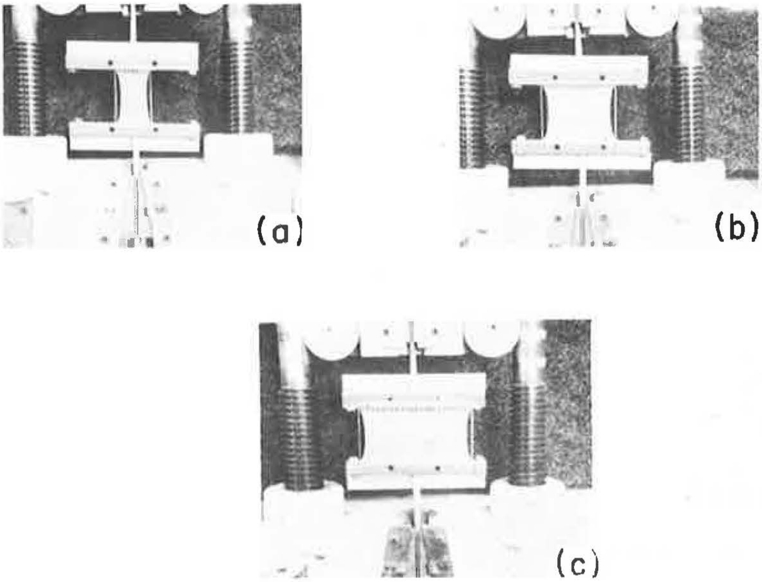

Figure 1. Marked specimens strained 100 percent: (a) 2-in. specimen, (b) 4-in. specimen, and (c) 6-in. specimen.

The photoelastic pictures (Fig. 2) bear out the results shown by Figure 1. These photoelastic pictures must also be considered as only qualitative, principally because of the rapid stress-relaxation rate of the translucent specimens.

Tests of ultimate strain and modulus of elasticity were also conducted in the experimental phase of this work. The results of these tests are shown in Table 2. There is practically no difference in the values of modulus or ultimate strain for the different size specimens tested. This appears to be consistent with the small variation in the stress in the f_1 direction (Table 1) since the stress in this direction is the value recorded by the testing machine.

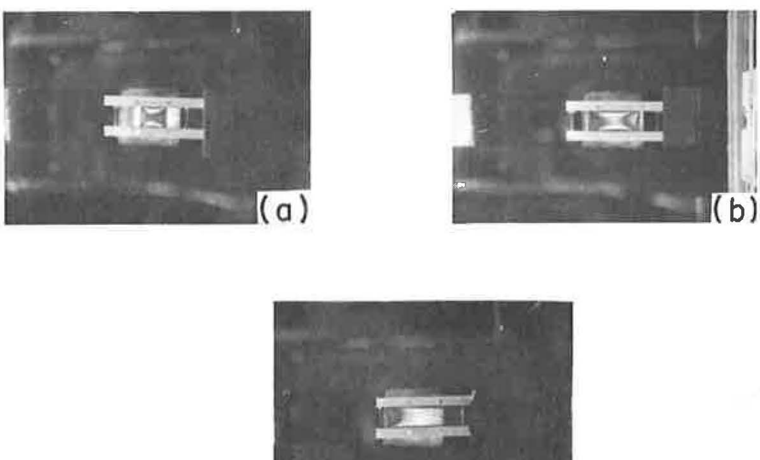

Figure 2. Patterns of stress in sealant specimens at 25 percent elongation: (a) 2-in. specimen, (b) 4-in. specimen, and (c) one-half length of 6-in. specimen.

TABLE 2

Specimen Length (in.)	Load (lb)	Gross Area (sq in.)	f_1 (psi)	Necked-Down Area (sq in.)	t_1 (psi)	Mod. of Elasticity (psi)
2	49	1.5	33	0.75	66	15
4	101	3.0	34	1.5	68	15.3
6	152	4.5	34	2.24	68	15.6

CONCLUSIONS

Intuition would seem to indicate that a longer sealant specimen would be more representative of actual use conditions than the extremely short specimen. The calculations included here indicate that the 2-in. specimen shows stresses that are 25 percent low. An increase of length of the specimen to 6 in. would reduce this error to approximately 10 percent. A specimen length greater than 6 in. would reduce the error still further, but testing equipment size would make the specimens very difficult, if not impossible, to handle. It is also true that the gain in accuracy beyond this point is subject to question because of the scatter in experimental data.

Pictures of the marked and strained specimens indicate that the 6-in. specimen has a central portion of 50 percent of the specimen length which is undisturbed by the effects of end neckdown. Photoelastic pictures appear to bear out this statement.

It is difficult to draw any conclusion from the results of modulus and ultimate strain tests. A first glance would indicate that the results are completely independent of specimen length. However, the stress indicated by these tests is in the direction of the applied load only.

It is recommended that the longer specimen be used whenever possible in testing work, since it appears to give results more representative of field conditions.

REFERENCES

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