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SOME ENGINEERING PROPERTIES OF BUILT-UP
ROOFING

BY
P. M. JONES

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Les fentes qu'on a souvent remarquées dans les toitures plates au cours des récentes années ont incité la Division des recherches en bâtiment à effectuer des études spéciales pour déterminer les causes de ces graves ennuis. Des spécialistes ont donc procédé à la détermination minutieuse de certaines propriétés techniques des éléments employés pour fabriquer les toits plats et de la couverture imperméable dans son ensemble. Pour faciliter la détermination des propriétés en question, une technique a été mise au point, laquelle permet d'appliquer la couverture imperméable au moyen d'un rouleau et un dispositif spécial d'adhérence a été mis au point pour les études sur la résistance à la traction. Ces études ont été effectuées à 75°F et à -20°F et deux cadences de traction ont été employées.

Les résultats obtenus permettent d'affirmer que le bitume joue un rôle secondaire dans la résistance de la couverture imperméable. Aux deux températures précitées les feutres assurent la résistance de cette couverture de 80 à 90%. En fait, la résistance s'est améliorée de 70 à 250% lorsque la température est passée de 75°F à -20°F. Le rôle secondaire joué par le bitume a été confirmé par un médiocre fluage et une faible résistance à l'effet d'entaille.

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SOME ENGINEERING PROPERTIES OF BUILT-UP ROOFING

By P. M. JONES¹

SYNOPSIS

The prevalence of splitting in built-up roofing during recent years has prompted special studies to be undertaken by the Division of Building Research to determine the causes for these serious failures. The determination of certain engineering properties of the components used in built-up roofing and the complete membrane have received special attention. To determine these properties, a roller-coating technique was developed to prepare membranes and a special grip arrangement was constructed for the tensile studies. These studies were made at 75 F and at -20 F, using two rates of straining.

The results emphasize the secondary role of the bitumen in the strength of the membrane. At both temperatures the felts contribute 80 to 90 per cent of the strength of the membrane, although the actual strengths increased by 70 to 250 per cent as the temperature changed from 75 F to -20 F. The small amount of creep and of notch sensitivity also serve to confirm the secondary role of the bitumen.

Some construction components are nonload-bearing and are not normally designed to carry a load. Some of the materials that make up these components, however, may become strained due to movements of the structural elements or deformations due to temperature and moisture changes. A roofing membrane can be classed as a nonload-bearing material. In common with other materials of this class little information is available on its strength and deformation properties, and the stress-strain properties of the membrane can be important in determining its performance ability.

Recent experience with serious splitting of built-up roofing membranes believed to have resulted from cold weather conditions with little snow has raised

questions about the shrinkage and extensibility of roofing materials at low temperatures and has prompted a study of these properties under controlled conditions in the laboratory. Techniques for preparation and loading of roof samples had to be developed and these are now reported, together with some of the results obtained for a limited number of materials and temperature conditions.

MATERIALS AND TESTING PROCEDURE

Samples of roofing membranes with uniform applications of bitumen were required for the testing program. It was found that membranes prepared on a roof varied considerably; samples prepared on a small scale using a mopping technique were also thought to be unsuitable. A simple roller-coating technique was developed which had the added advantage of ensuring that all

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portions of the felt were coated with bitumen. The procedure was used in the preparation of samples from two bitumens and three types of felts. A commercial-grade roofing pitch was used in conjunction with a tar-saturated roofing felt. A commercial-grade, dead-level asphalt was used with an asphalt-saturated rag felt and an asphalt-saturated glass felt. All materials were of good quality, produced by well-known manufacturers, and complied with the requirements of the pertinent specifications of the Canadian Standards Assn.² The asphalt had a softening point of 145 F; the coal-tar pitch had a softening point of 140 F. The brittle-point characteristic of these

The roller-coating method used rollers 13 in. long and $4\frac{1}{2}$ in. in diameter. The surfaces and ends of these rollers were covered with a silicone-treated aluminum foil to serve as a release agent. The roller was then wrapped with one turn of roofing felt which was held in place by a piece of adhesive tape applied along the butt joint in the felt. The assembly was placed in a bath of heated bitumen (Fig. 1) and rotated, to coat the felt with bitumen. The amount of bitumen applied in this manner was controlled by the temperature of the bath and the rate of rotation of the roller. A satisfactory rate of application was obtained with a temperature of 430 F when as-

FIG. 1.—Preparation of Built-up Roofing Membranes.

two bitumens was measured using a modified Fraass test,³ a value of -5 F was obtained for the asphalt, compared with a value of $+51$ F for the coal-tar pitch.

² "Asphalt Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs, 15-lb Type," A123-6 (1953); "Asphalt for Use in Constructing Built-Up Roofing, Type 1," A123-7 (1962); "Coal-tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs, 15-lb Type," A123-8 (1953); "Coal-tar Pitch for Roofing Dampproofing and Waterproofing, Type A," A123-13 (1953); "Asphalt Saturated Felted Glass-Fibre Mat for Use in Construction of Built-Up Roofs Type 1," A123-17 (1963). Canadian Standards Assn., Eastview, Ont., Canada.

³ P. M. Jones, "The Use of a Brittle-Point Test in Low Temperature Studies on Asphalts," *Proceedings*, Canadian Technical Asphalt Assn., 1962, pp. 15-24.

phalt was used and 320 F when coal-tar pitch was used. It was possible to prepare samples containing about 21 lb of bitumen per 100 sq ft, well within a range of ± 10 per cent. After the roller was lifted from the bath the felt was removed by stripping back the adhesive tape, allowing the felt to fall from the roller, with the bitumen side down, onto a flat sheet of aluminum foil coated with a release agent. The felt was then rolled to remove unevenness in bitumen thickness. A second coated felt was then prepared and applied to the first, to achieve a 2-ply membrane. Continuation of this procedure could produce membranes with any desired number of plies. Membrane samples 2 plies thick and about 12 in. square were obtained in this way for

testing. When the membrane had cooled, samples for tensile studies were cut with a jig and a sharp knife to produce a specimen with the dimensions shown in Fig. 2.

The tension testing apparatus (Fig. 3) consists of a small horizontal tensometer

To measure the deformation of the specimen during testing, a strain gage was used, as shown in Fig. 3. The gage length of 2 in. is defined by two pins which penetrate to the center of the specimen. Expansion or contraction of

FIG. 2.—Tension Specimen with Grip Arrangement.

FIG. 3.—Tensile Testing Apparatus.

with an added motor drive and gear box which enables various rates of straining to be used. The load on the specimen in the tensometer is transmitted to a spring beam, the deflection of which is proportional to the load. This deflection is measured by the movement of a column of mercury in a glass tube.

the specimen produces a change in the distance between the pins which causes movement of the core of a differential transformer. This results in a change of flux which is recorded in a magnified scale on a recorder. This strain gage is calibrated so that a movement of the sample of 0.0001 in. can be measured.

A special gripping arrangement had to be designed to hold the specimens in the tension testing apparatus. This was necessary because the nature of the materials made using the conventional serrated grips impossible since they were unable to hold the membrane without movement of the intermediate material. The bitumen coating interfered with proper gripping, the intermediate plies had a tendency to slip, and the results

which they can be shifted transversely to align the specimen with the line of load application. The yokes are attached to the loading tackle of the tension testing apparatus.

The amount of coating bitumen has very little effect on the strength of the membrane and it is anticipated that a 3- or 4-ply system would be proportionately stronger than the 2-ply system used throughout this study. The 2-ply

FIG. 4.—Breaking Strengths of Built-up Roofing Tested at 75 F at a Rate of 0.050 in. per min.

were generally unsatisfactory with many specimens breaking in the grips. Also, with conventional serrated grips, the geometric axis of the specimen cannot possibly be adjusted to coincide with the axis of load application. The grip arrangement finally adopted (Fig. 2), which obviates these problems, employs a commercial wire belt-lacing embedded in the ends of the specimens and then coated with an epoxy cement. The belt lacings are attached to specially devised mating adapters by steel hinge pins. These adapters are held in yokes in

membranes do not contain any extra bitumen in the form of a flood coat, and when the saturated felts were examined for tensile properties, 2-ply samples were also used. Tensile studies were made on three types of membranes and also on three types of felt without bitumen as an interply adhesive. Specimens were prepared both in the length or machine direction of the felt manufacture and across this machine direction. Testing was carried out at two temperatures, 75 and -20 F, and at two rates of strain, 0.050 and 0.001 in. per min head speed.

EFFECT OF MEMBRANE

The first series of tests was made at a temperature of 75 F and at a strain rate of 0.050 in. per min head speed. The results are shown in Fig. 4 and a sum-

quite high with the rag felt samples, but smaller in the case of the glass felts.

A comparison of the results for the saturated felts with those for the membranes shows that the strength of the

TABLE 1.—EFFECT OF MEMBRANE ON BREAKING STRENGTHS OF BUILT-UP ROOFING.

Sample	Direction	Saturated Felts		Membranes	
		Breaking Strain, per cent	Breaking Load, lb per in.	Breaking Strain, per cent	Breaking Load, lb per in.
Asphalt rag.....	lengthwise	0.85	73	1.03	75
	crosswise	1.45	32	2.33	40
Asphalt glass.....	lengthwise	1.00	41	1.40	45
	crosswise	1.00	27.5	1.70	36
Coal-Tar pitch rag.....	lengthwise	1.30	67.5	1.70	77
	crosswise	1.80	27	2.41	29

FIG. 5.—Comparison of Breaking Loads of Built-up Roofing at 75 F and -20 F.

mary of the breaking strengths is presented in Table 1. The tabular values are the average of three determinations; the curves in Fig. 4 are for a typical sample and are actual determined values. In all cases the strength of the felts is higher in the machine direction than in the cross direction. The difference is

membranes is largely the result of the felt strength. The rag felt in the length direction contributes 96 per cent of the strength of the membrane; in the cross direction 81 per cent is contributed by the saturated felt. With glass membranes the saturated felt contributes 80 per cent of the strength in the length direction

and 76 per cent in the cross direction. With coal-tar pitch samples, the saturated felt contributes 88 per cent of the strength of the membrane in the length direction and 94 per cent in the cross direction.

The influence of the felt fiber is illustrated in Fig. 4. The rag felt samples in the length direction exhibit almost identical stress-strain curves and are not greatly modified by the use of different bitumens. This was also the case for the samples of rag felts in the cross direction, the coal-tar pitch and asphalt-saturated felts having similar properties in this

felts, particularly with the rag samples. The asphalt-rag membrane shows an increase in the breaking load of the membrane of 200 per cent in the length direction and 250 per cent in the cross direction. The coal-tar pitch membrane increased in breaking strength by 130 per cent in the length direction and 230 per cent in the cross direction. The asphalt-glass membranes show increases of 70 per cent in the length direction and 50 per cent in the cross direction.

The differences between the various types of felt increase as the temperature is lowered. The contribution of the felt

TABLE 2.—BREAKING STRENGTHS OF BUILT-UP ROOFING AT -20 F.

Sample	Direction	Saturated Felts		Membranes	
		Breaking Strain, per cent	Breaking Load, lb per in.	Breaking Strain, per cent	Breaking Load, lb per in.
Asphalt rag.....	lengthwise	1.04	221	1.05	237
	crosswise	1.31	115.5	1.18	143
Asphalt glass.....	lengthwise	0.70	40	1.12	76
	crosswise	0.97	44	1.11	57
Coal-Tar pitch rag.....	lengthwise	0.47	148.5	0.62	176
	crosswise	0.32	69.5	0.45	97

respect. The rag felts saturated with coal-tar pitch and asphalt-saturated rag felt, however, were obtained from different manufacturers and it would be expected that the unsaturated rag material is different in each case.

EFFECT OF TEMPERATURE

To determine the effect of low temperature upon the tensile properties of the materials, specimens were tested at a temperature of -20 F and at a strain rate of 0.050 in. per min. A comparison of the breaking loads at this temperature with those at 75 F is shown in Fig. 5, and a summary of the breaking strains and breaking loads is given in Table 2. These results show the large increase in the breaking load of the membranes and

strength to the strength of the membrane, however, is proportionately unchanged, with the exception of the glass felts which contribute less to the strength of the membrane. In the length direction the glass felt contributes only 52 per cent of the load and in the cross direction, only 74 per cent. This indicates that the strength is to some extent controlled by the load-carrying capacity of the coating asphalt and that a failure of the asphalt results in failure of the membrane. Some evidence of this was noticed during some tests at slower rates of loading. With asphalt-rag membranes, the asphalt split at about half the breaking load but, although the cracks penetrated to the rag layer, no premature failure was noticed. With the asphalt-glass membranes, how-

ever, a crack in the asphalt appeared to result in failure of the sample almost immediately.

The breaking strains in general decreased as the temperature was lowered

EFFECT OF RATE OF
LOAD APPLICATION

Since bitumens are viscoelastic materials, it might be expected that, to the extent that they carry load directly,

TABLE 3.—EFFECT OF RATE OF LOADING UPON STRENGTH OF BUILT-UP ROOFING.

Sample	Direction	Temperature: 75 F				Temperature: -20 F			
		Rate of Loading: 0.050 in. per min		Rate of Loading: 0.001 in. per min		Rate of Loading: 0.050 in. per min		Rate of Loading: 0.001 in. per min	
		Breaking Strain, per cent	Breaking Load, lb per in.	Breaking Strain, per cent	Breaking Load, lb per in.	Breaking Strain, per cent	Breaking Load, lb per in.	Breaking Strain, per cent	Breaking Load, lb per in.
Asphalt rag	lengthwise	1.03	75	1.71	47	1.05	237	1.28	220
	crosswise	2.33	40	3.77	27	1.18	143	1.46	121
Asphalt glass	lengthwise	1.40	45	2.10	22	1.12	76	0.88	66
	crosswise	1.70	30	2.00	24	1.11	57	0.98	49
Coal-Tar pitch rag . . .	lengthwise	1.70	76	...	...	0.62	176	0.94	183.5
	crosswise	2.41	29	...	...	0.45	97	0.63	96

FIG. 6.—Effect of Rate of Straining on Breaking Strengths of Membranes at -20 F.

from 75 F to -20 F. All the asphaltic membranes have almost identical breaking strains of 1.1 per cent at -20 F, whereas the coal-tar pitch membranes are about 0.5 per cent at this temperature.

their contribution to strength would be varied by changing the rate of straining. To investigate this, tests of the membranes were repeated at the much lower straining rate of only 0.001 in. per min head speed. This produced times to fail-

ure of 2 to 3 hr. Specimens were tested at both 75 F and -20 F except for the coal-tar pitch samples which were not tested at 75 F. A summary of the breaking loads and breaking strains is given in Table 3. In Fig. 6 the stress-strain curves for the membranes at -20 F are shown. The results in Table 3 show that the lower rate of loading results in lower breaking loads at 75 F. Figure 6 demonstrates that at -20 F only a small amount of viscous flow is evident from the slightly lower slope of the stress-strain curve. The ultimate breaking strength is unchanged, except that the

temperature have up to 40 per cent less strength than the original unnotched specimens. This relatively small notch sensitivity tends to confirm the secondary role of the coating bitumen in contributing to strength, even at low temperatures when it is quite brittle. These results also tend to minimize the possible importance of brittle failure as a factor leading to splitting of roof membranes.

DISCUSSION

The results show that the felt plays a major role in the strength of the mem-

TABLE 4.—EFFECT OF NOTCH UPON BREAKING LOAD OF ROOFING MEMBRANES.

Sample	Direction	Per Cent Reduction in Breaking Strength Based on Standard Specimens	
		At 77 F	At -20 F
Asphalt rag.....	lengthwise	0	36
	crosswise	0	10
Asphalt glass.....	lengthwise	0	19
	crosswise	0	15
Coal-Tar pitch rag.....	lengthwise	0	13
	crosswise	0	0

coal-tar pitch samples have a much higher breaking strain at the lower rate of straining.

EFFECT OF NOTCH

To determine the possible effect of cracks or flaws in initiating splitting failures as a result of embrittlement in an actual roof, a series of notched specimens were tested. These were 2 in. wide and were notched symmetrically at the center to produce a net section 1 in. wide. They were tested at 75 F and -20 F at a speed of 0.050 in. per min head speed. The results, shown in Table 4, indicate that there is no notch sensitivity at room temperature and that, depending upon the bitumen type of felt used, notched specimens at the lower

brane. The fact that at -20 F the samples have almost the same tensile properties regardless of rate of straining indicates that little creep of the bitumen occurs at this temperature. But at 75 F, creep would appear to have an influence since, at the slow loading, the breaking loads are sharply decreased while the corresponding strains are increased.

Although it is still difficult to relate the results to the splitting of real roof membranes, it is of interest to note that, while the breaking strains decreased, the strength of the membranes increased with reduction in temperature. It was apparent that to begin to assess the strains that might be occurring in real roofs the shrinkage due to lowering the temperature would have to be deter-

mined, for comparison with the strains which the membranes exhibit at breaking. Attempts to make such measurements and further consideration of them indicated, however, that this was not a simple matter. The temperature effects themselves are complicated by the nature of the membrane, which may have to be regarded as having three components: fiber, saturant, and coating. Apparent thermal contraction may therefore have to be related to load as well as to duration and rate of loading since, in practice, membranes are undoubtedly loaded progressively in tension as they cool and shrink. Another complication is introduced by the presence of water in felts so that dimensional changes upon cooling will be a function of moisture content also. Preliminary experiments indicate that, as a further complication, the shrinkage effects may not be linear with temperature but may increase at a greater rate below the freezing point.

Measurements of shrinkage are being continued but have not progressed to the point of reporting.

CONCLUSIONS

The following facts have been shown:

1. The breaking load of a rag membrane saturated and coated with either asphalt or coal-tar pitch and tested in the length direction is double that of the cross direction.
2. The breaking loads of the asphalt-glass membranes are equal in each direction and are roughly the same as those

of the bitumen rag membranes when tested in the cross machine direction.

3. The breaking loads of the bitumen-rag membranes were tripled when the temperature was decreased from 75 F to -20 F, and over the same range the breaking load of the asphalt-glass membranes increased by about 70 per cent.

4. The breaking strains varied as the temperature changed. The coal-tar pitch membranes in each direction had a marked decrease in breaking strain from 1.7 per cent at 75 F to 0.5 per cent at -20 F. The asphaltic membranes in the cross machine direction decreased from 2.3 per cent at 75 F to 1.2 per cent at -20 F for the rag and from 1.7 per cent at 75 F to 1.1 per cent at -20 F for the glass. The asphaltic membranes in the length direction showed little or no change in breaking strain.

5. The membranes have approximately the same breaking load as the bare felts, indicating that the strength of the roof depends largely upon the strength of felts and that the coating bitumen serves mainly as a waterproofer.

Acknowledgments:

The author acknowledges with appreciation the advice and encouragement given to him by N. B. Hutcheon, assistant director of the Division of Building Research. Appreciation is also due Mr. G. Quenneville for assistance with testing. This paper is a contribution from the Division of Building Research, National Research Council, Canada, and is published with the approval of the Director of the Division.

DISCUSSION

MR. W. H. GUMPERTZ¹ AND E. TONS.²

—The author deserves great credit for the useful contribution he has made in a field where a great deal of off-the-cuff opinions are supported by little concrete knowledge. His work should encourage further fundamental investigation into the physical properties of built-up roofing materials and the mechanical behavior of its components. For clarification and some questions, we would like to make the following comments, following the outline of the paper:

1. A 2-ply composite built-up roof may be convenient for testing, but it is not realistic. In a 4-ply specimen with flood coat, the weight percentage of the paper felt is only about half of that in the author's test specimens; this proportion tends to distort the relative effect of the felt and the mopping bitumen on the properties of the built-up roofing, especially at low temperatures.

2. The lacing type of attachment may allow some interply slippage and random variation of test results. It also makes use of dogbone specimens necessary. Experience indicates that not only will a rectangular specimen be simpler to prepare, but no testing difficulties will be encountered if the ends are anchored with a low-modulus mixture of epoxy resin. (Details of the procedure have

been developed by the writers and will be published soon.)

3. One statement in the paper is that the "coating (mopping)" bitumen has very little effect on the strength of the membrane, and that a 3- or 4-ply system should be proportionately stronger than the 2-ply system. We cannot subscribe to this conclusion since the mopping asphalt, as discussed above, is only a small part of the total membrane in the author's specimens. Since the paper or fibrous glass felts will not be affected substantially by a change in temperature, the steep increase in membrane and felt strength from 75 F to -20 F can be explained only by the changing viscoelastic behavior of the bitumens, both as impregnant and as mopping material. At temperatures below freezing, the properties of membranes are dominated largely by its impregnant and mopping bitumens.

4. The author shows a general increase by a factor of 4 in the tensile strength of specimens by dropping the temperature for 75 F to -20 F, except in the case of glass fibrous felts, where the strength increase is only 1.5- to 2-fold. Tests by us and by Owens-Corning Fiberglas Research Center seem to indicate that the factor of 4 applies to all types of membranes. This seems to correlate with the theory that the total bitumen content strongly affects the strength characteristics of all types of membrane at the lower temperatures.

5. The author's observation that the

¹ Principal, Simpson Gumpertz & Heger, Inc., Cambridge, Mass.

² Assistant Professor, Department of Civil Engineering, Massachusetts Inst. of Technology, and consulting engineer, Simpson Gumpertz & Heger, Inc., Cambridge, Mass.

asphalt-glass membrane fails as soon as the asphalt fails may be interpreted in a different way. The greater modulus of elasticity of the glass fiber might prevent a visible bitumen failure for some time while the load increases; the cracking of the bitumen occurs near the final failure point in the glass felt.

6. Notch tests made on symmetrical cross-sections appear to have little additional significance over simple tension tests; the statement about the importance of the brittle failure as a factor in roof splitting appears to be a non sequitur.

7. The author seems to disregard roof movement, and especially differential movement in discrete areas, as a prime cause of roof splitting in winter. So far no evidence has been submitted that would prove that a built-up roofing membrane can pull itself apart because of uniform thermal movements; highly localized strains, due to dimensional changes in the size of underlying cracks or joints in the support have again and again been shown to be responsible for most if not all tensile roofing failures.

8. (See Table 2 of the paper.) The increase in strength of glass-fiber membrane over that of glass-fiber felts is 30 per cent in the transverse direction, but 90 per cent in the longitudinal direction. Since the only difference between these two groups is in the mopping asphalt (which is nondirectional), this discrepancy suggests a need for additional tests.

It is hoped that these tests will be continued and will be complemented by others. More should be learned about the connection between strength, failure strain, and ability of membranes to bridge local cracks.

MR. P. M. JONES (*author*).—The interest and critical comments of Messrs. Gumpertz and Tons are appreciated.

I believe, however, that several of the points are repetitive and so I will not reply to each but will discuss the general questions that have been raised.

One of the more important advantages of the 2-ply system is the ease with which interply slippage can be overcome; further studies have indicated that 3- and 4-ply membranes are proportionately stronger. The use of a flood coat is desirable in service and it obviously must be retained in any testing of actual roof sections. Except for studies to assess the basic engineering properties of the membrane this additional quantity of bitumen adds little but mass and thickness to the sample.

The use of a lacing attachment eliminates slippage of interply material because the grips penetrate through every ply. This is not true of the system which is suggested by Messrs. Gumpertz and Tons, and I cannot accept the statement that a rectangular specimen will give no testing difficulties; I would anticipate great difficulty with such a specimen at low temperatures.

The effect of the bitumen in strength considerations appears to be small, but is very noticeable in the breaking strains of the membranes and this is shown in Table 2, which indicates that at -20°F all asphaltic membranes have the same breaking strain regardless of the nature or fiber direction of the felt.

Brittleness can be considered as the property of failure with little or no deformation and, in the case of very brittle materials like glass, failure can be precipitated by a small defect. It was to determine if this stress sensitivity existed in built-up roofing that the notch test was used. The slight decrease in breaking strength was not considered sufficient to enable a roof failure to be triggered by a small flaw or defect.

Messrs. Gumpertz and Tons have

misinterpreted my intent when they state that I disregard building movement. This paper is intended to give information on the nature of a roof membrane. A knowledge of the limiting stresses and strains for materials used in roof construction would enable design considerations to be given to building movements and to other sources of strain

such as temperature and moisture changes.

The apparent confusing variation in the results of the glass fiber membranes given in Table 2 can be explained by the splitting of the asphalt coating for it will be noted that the breaking strain is the same in each direction of the glass membranes.