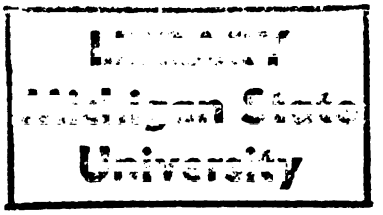

This is to certify that the

thesis entitled

The Effects of Tensile Strain on the Performance of High-Barrier Retortable Pouch Material

presented by

Scott Allan Morris

has been accepted towards fulfillment
of the requirements for

M.S. degree in Packaging

Major professor

Date 2-13-87

THE EFFECTS OF TENSILE STRAIN ON THE PERFORMANCE OF HIGH-BARRIER RETORTABLE POUCH MATERIAL

By

Scott Allan Morris

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Submitted to
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ABSTRACT

THE EFFECTS OF TENSILE STRAIN ON THE PERFORMANCE OF HIGH-BARRIER RETORTABLE POUCH MATERIAL

By

Scott Allan Morris

The oxygen permeation rate of some materials can be shown to vary in proportion to mechanical strain. The oxygen permeation rate affects the shelf-life of packaged foodstuffs and other products. It follows that the amount of strain that a package encounters will relate to some degree of quality reduction due to an increase in oxygen permeation rates.

This study investigated the effect of tensile strain on the barrier properties of the composite material used in retortable food pouches. The effects of variations in material orientation, strain-rate, and degree of strain on changes in the material's oxygen permeation rate were investigated. Additionally, a finite element model of the test samples was constructed to estimate the stress in the sample structure.

The data gathered during this experiment conclusively showed that straining the material did increase the material's oxygen transmission rate, which is crucial in the long-term storage of oxygen-sensitive products.

DEDICATION

This brief tome is dedicated to my parents, Dr. Allan J. Morris and Frances M. Stearns-Morris and my sole sibling, Pamela, whose patience and generosity have not always been reciprocated.

ACKNOWLEDGEMENTS

None of this would have been possible without the continued support and good humor of the thesis committee: Rick Brandenburg, Bruce Harte, and my major advisor, Julian Lee. Assistance from Larry Segerlind with the numerical model, and John Gill with the statistics is also gratefully acknowledged. The rest of the staff and faculty at the School of Packaging also recieve my heartfelt thanks for their assistance in everything, period. Finally, all of my fellow students, past and present,(and everyone else) that I have had the pleasure of associating with are acknowledged for the enriching of my life...there isn't room for everyone's name, but I haven't forgotten.

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INTRODUCTION

The Development of high-barrier flexible packaging materials has resulted in flexible packages that may be thermally processed in a manner similar to the metal cans and glass bottles that they are intended to supplant. These retortable packages (pouches, trays, and the like) are capable of providing a low-cost, lightweight package with good shelf-life and the potential of replacing cans and jars in specific applications. Their widespread acceptance by food companies, to date, has been hampered by the cost of production equipment, and the slow production speed of filling lines.

Little is known about the survivability of these new types of containers in production and distribution. Their predecessors--cans, jars, and bottles--will usually give a clear indication of the loss of integrity by either the loss of internal vacuum or the destruction of the package structure. Unlike the cans, jars and bottles that they replace, these retortable containers have the possibility of partial loss of their barrier properties in localized areas with attendant quality or safety deterioration. The results of this may be premature nutrient loss, contamination, or flavor deterioration. Thus, a flexible retortable pouch that has been subtly damaged may be as

ineffective a barrier as a container that is leaking its contents, yet will give no overt indication of damage.

In this study, the exhibited changes of barrier capability as a function of simple uniaxial strain give a clearer notion of the mechanisms by which the material degrades before failure, and the sorts of damage mechanisms one might expect to be present as a result of handling and transportation.

FAILURE MECHANISMS

In most applications, a barrier film that is subjected to mechanical stresses can reasonably be expected to fail, given severe enough levels of abuse. What is not so clear are the effects of "sublimital" damage--damages that have no overt effect but will reduce the efficacy of the barrier material involved. The implication of this type of failure is that a product contained in a polymeric or a polymer-laminate composite is at risk of losing its protection from potentially damaging elements without any externally evident indication of failure.

In most situations, failure is usually associated with breaking or rupture of the container material, yet a packaging material that has lost its necessary barrier qualities has failed just as badly. Further, since there is no obvious indication that the contents have degraded, there is the risk of the contents being used after their shelf-life has prematurely expired. In the case of a food product that will visibly show quality changes (such as the oxidation browning of catsup), the harm to the consumer is usually minor even though the likelihood of a repeat purchase is reduced. If the product is a pharmaceutical or a medical diagnostic item, the harm to the "consumer" might

well be more severe than an affront to his palate.

The relationship between strain-induced orientation changes, and changes in the permeation and sorption values for a polymer film under various conditions is well known, although there is no precise predictive model for these changes under most circumstances[1,2,3,4,5]. Similarly, there is a wealth of data relating the morphological changes in polymeric materials to the variables involved in plastic deformation and reorientation from very low levels of strain to failure[6,7,8]. There is little information relating barrier failure to the morphological changes which occur in the areas where strain will induce discontinuities in the material.

The strain-induced morphological changes in semicrystalline polymers, and the attendant failure mechanisms are known to be dependent on the rate as well as the magnitude of the strain[9]. It has been shown that failure mechanisms of simple polymer sheets will fall into three broad classes which are contingent on the strain rate[8]. At very low strain rates, the polymer is able to reorient itself in the direction of the applied stress, changing its morphology from semicrystalline spherulites to highly oriented fibrillar strands with an attendant decrease in permeation and sorption rates and an increase in unit strength. This decrease in permeation has been exploited in the production of some types of biaxially

oriented beverage containers for the soft-drink industry. As the rate of strain increases, the material in the spherulites does not have the time to reorient itself, and the spherulites will begin to pull apart (a phenomenon termed "crazing")[10]. This process will generate microscopic voids in the interspherulitic boundaries, and it is at this point that some researchers consider their investigation into strain-related permeation changes at an end because the permeation mechanism diverges from a strict sorption-diffusion-desorption model. This is unfortunate because at this point that a large number of practical applications begin to surface.

At still higher rates of strain there is insufficient time for the spherulites to reorient their internal structure and intraspherulitic fracturing begins to occur. This fracturing will also cause a significant decrease in the barrier capability of the polymer due to its increasing porosity. It must be mentioned that a panoply of other factors will affect the effects of strain rate. Most noteworthy of these is temperature, which directly affects the segmental mobility of the polymer matrix, and thus mediates the modes of failure described above[11]. Additionally these temperature effects will cause the thermally processed containers to exhibit changes during and after processing which will affect the physical stability of containers.

The destruction of barrier properties in a metallic laminate has an additional set of complications. The first of these is the adhesion between the layers. Since the adhesive is a polymeric substance as well there may be additional strain-dependent effects exhibited in the adhesive layers. Poor bonding, or a significant shift in the bonding characteristics of the adhesive layer will affect the isotropic nature of the laminate[1]. Moreover, the metallic layer provides most of the barrier properties in the laminate. The ultimate plastic deformation for aluminum foils is approximately 35%[12] while for most polyolefin polymers the minimum (at sufficiently low strain rates) is several hundred percent[13]. In the event that the metallic layer is well bonded, the metallic layer should fragment in the area where the strain occurs, negating a large portion of the foil's barrier contribution. If the foil layer is poorly bonded the material will exhibit a large degree of anisotropicity, and the metallic layer will fracture in a direction approximately normal to the applied stress, as if it were an isolated piece of foil being supported by the polymer layers[1]. In either case the inelasticity of the metallic layer relative to its polymeric companions would lead to the expectation of failure in the metallic layer after a relatively small degree of strain, and that this failure should be relatively rate independent.

The resulting combination of effects that one finds in

the laminate material examined in this study points to the expectation that there would be a mode of barrier degradation that would vary according to both the degree and rate of strain applied. The degradation should result from two types of effects; Those related to the destruction of the foil layer at a (relatively) low degree of strain, and those related to the previously described rate-dependent failure of the polymer layers occurring at higher percentages of strain than that which fragments the foil layer.

It should be noted that newer types of laminates (where a high-barrier polymer film replaces the foil layer) for thermally processed food applications may not exhibit the same effects because of the substitution of a plasticized polymeric barrier layer for the foil layer. However this makes the rate dependent effects, as well as the thermal history of the material more important.

EXPERIMENTAL PROCEDURES

Initial Tensile Measurements

Samples of American Can Co. retort pouch material (Material Number K125 44-050) were cut to shape using a template (Figure 1) and then subjected to tensile stress in an Instron Tensile Tester (Model #1114). The failure points were determined for each rate and orientation of the material and the average strains at failure were used in the calculation of the 10%,50%, and 90% of failure strain extension (Appendix A, Tables 3-8).

Tensile Treatment

The experimental samples were stored at 73°F and 50% relative humidity for at least 48 hours prior to testing. Samples were then cut from the stock to be tested using a template (Figure 1) to ensure uniform and symmetrical dimensions in the sample.

The shape of this template differs from most of those used in ASTM tensile tests of flat materials. The reason for a sample shape of this type is to concentrate the stress in the sample along a single transverse band in the center of the sample material rather than along the length of a long strip of material. This, in turn, allows a

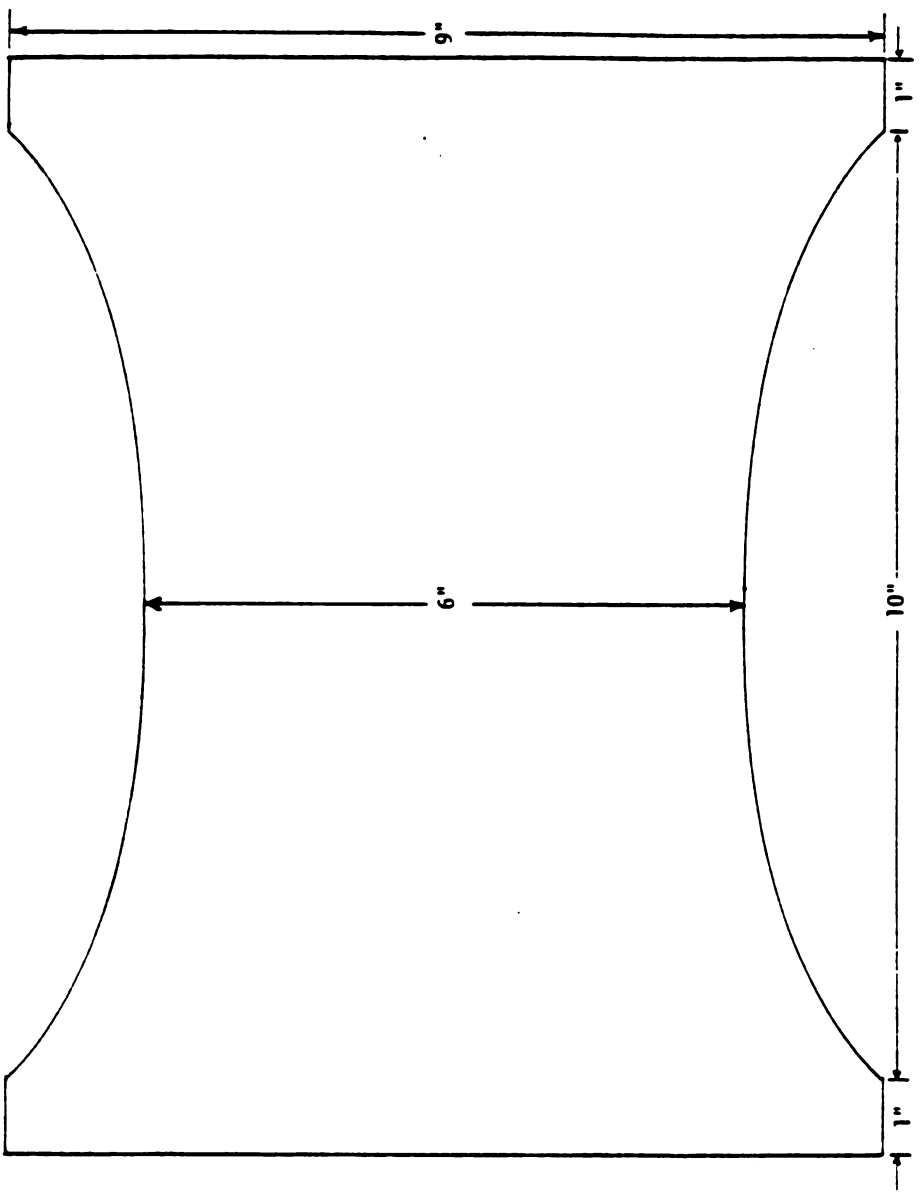

Figure 1. Diagram of sample-cutting template.

sample to have the resultant strain placed in a relatively specific area for the later testing of oxygen transmission rates.

The cut samples of flat stock were then placed in the jaws of the Instron tensile-tester and subjected to strain amounting to 10%, 50%, and 90% of the mean failure strain extension as calculated above. Additionally, samples at each of the above strain levels were strained at 0.1, 1.0, and 10.0 inches per minute. The materials thus tested were sampled from the machine direction (tensile force applied along the length of the spooled material) and the cross machine direction (in a direction planar-normal to the first). This was done to determine any effects of material pre-orientation on the stress-related barrier failure. Three samples of each direction, rate, and orientation were tested, for a total of 54 tested samples.

Because of the extreme width of the samples at each end, the jaws of the tensile tester had to be widened by means of a set of extension clamps (Figure 2). Once the samples had been strained, crosshead travel was immediately reversed so that the reorientation time of the material would be limited to approximately the amount of time that the material was actually under extension in the tensile tester.

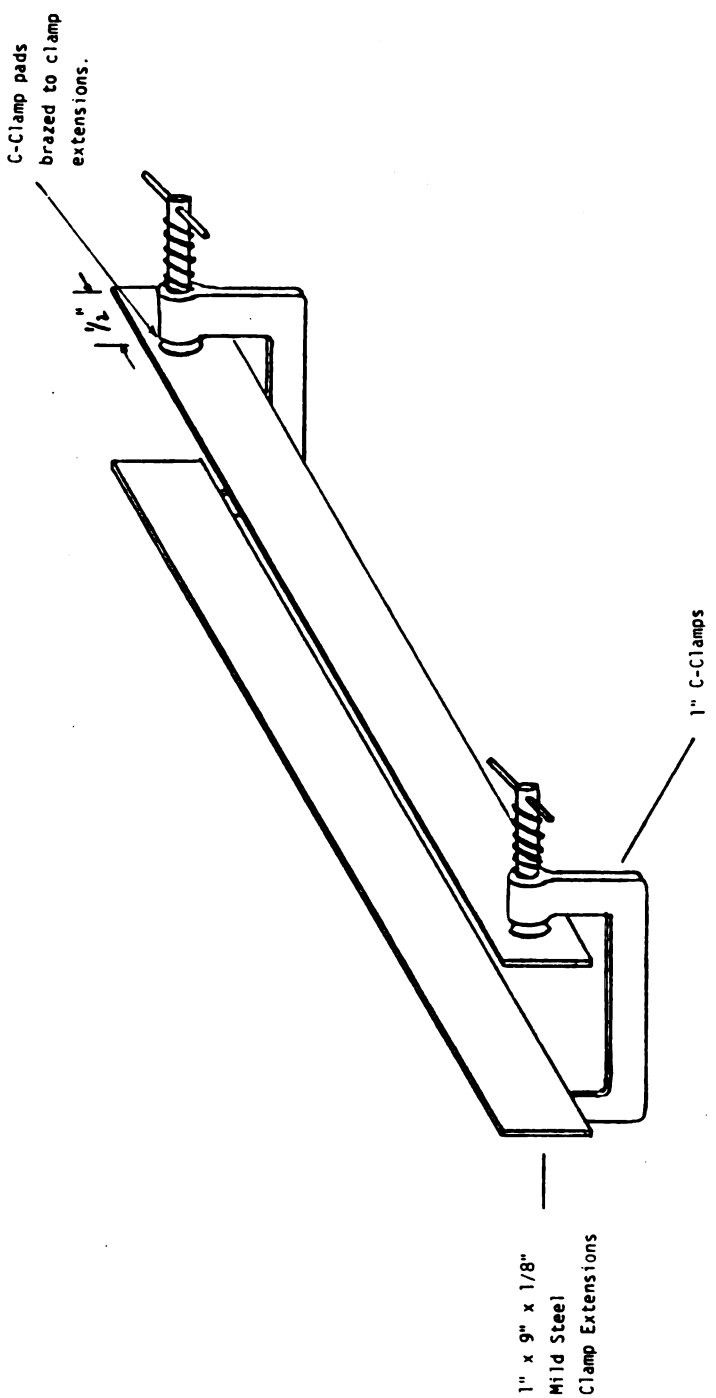

Figure 2. Diagram of clamp-extension assembly.

Oxygen Transmission Rate Testing

The strained samples were removed from the tensile tester, and the samples were stored for at least 24 hours to allow residual stresses to be relieved. The samples were then placed in the film testing cell of a Modern Controls OxTran oxygen transmission rate tester which uses a coulometric (catalyst-electrolyte) detector to determine the oxygen concentration of a the sweep gas in an isostatic test cell. The test cell used in this study exposes 100cm^2 of film to a flow of pure oxygen across the top of a sample, and a sweep gas (1% hydrogen in nitrogen) across the bottom. Thus a 1 atmosphere partial pressure gradient is established across the sample, and the oxygen permeating through the sample is carried off in the sweep gas to the coulometric cell where the hydrogen and oxygen are catalyzed into H_2O and a small DC voltage (in proportion to the amount of oxygen permeating the sample) which is then recorded.

The OxTran unit was calibrated using ASTM standard polyester film (NBS D-1470) to provide a calibration factor for the oxygen transmission rates. Each sample was allowed to equilibrate its transmission rate for a minimum of four hours, then an oxygen transmission rate (relative to the calibration film) was obtained for each sample (Appendix A, Tables 9-15). The resultant rates collected

were then plotted against rate and degree of strain for each orientation of the material (Figures 3-5.). Additionally, permeation rates for all variables in each of the two material orientations were also plotted (Figures 6,7).

The Numerical Model

A finite-element model of the sample was generated using the "Isoelastic" isoparametric-element elasticity program[14] in order to model the concentration of stresses in the tensile specimen (Figure 8.). This model utilizes experimentally obtained data (Appendix B) for the coefficient of elasticity and Poisson's ratio in 2-dimensions (thinning effects of strain were assumed to be negligible). The resulting plot (Figure 9.) is a series of isostatic contours representing the stress occurring in the sample. The intent of this is to simply confirm that the design of the tensile specimen will result in proper focusing of the stress applied to the sample.

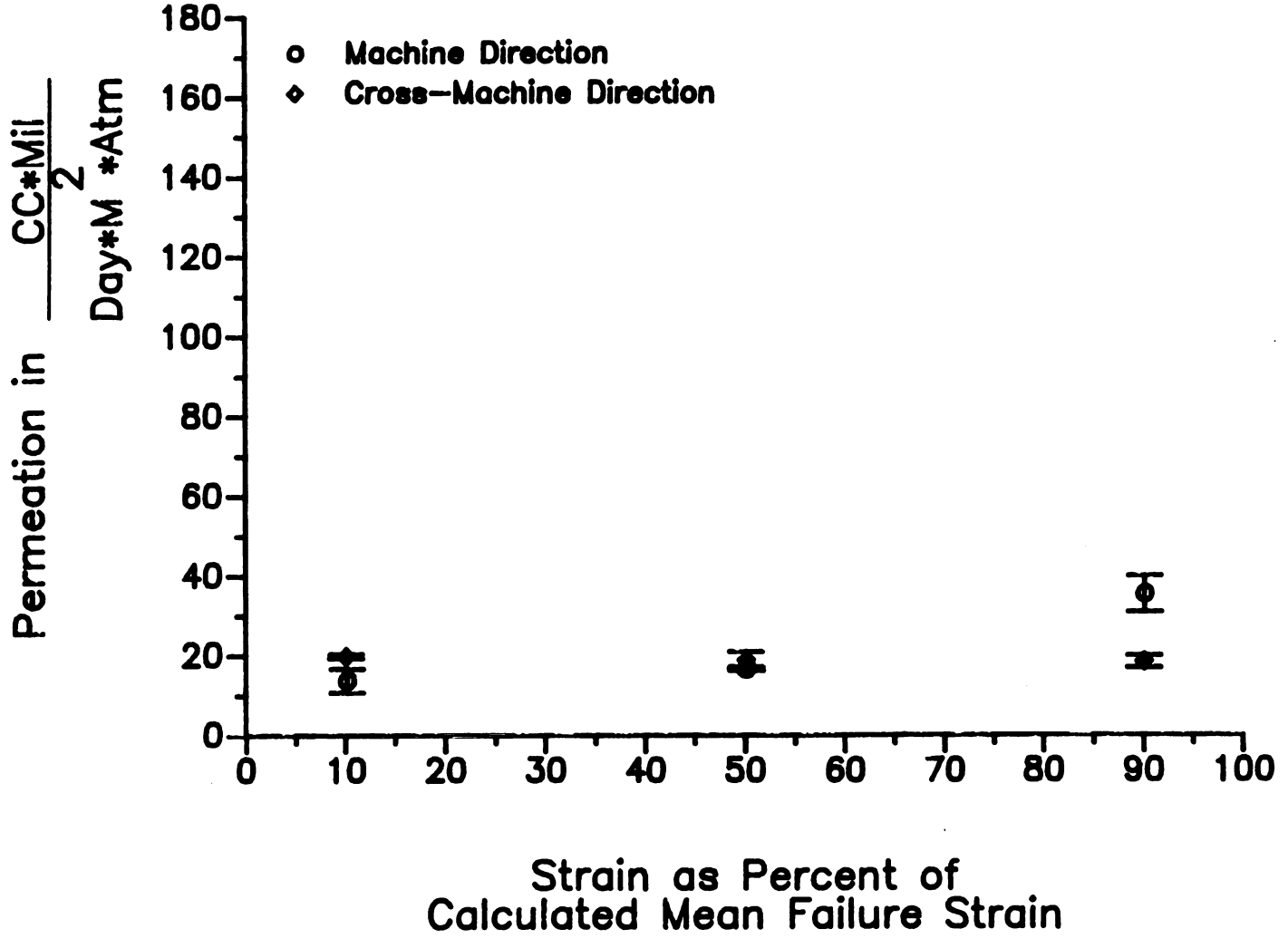

Figure 3. Graph of oxygen permeation rates versus orientation and strain at 0.1 in/min.

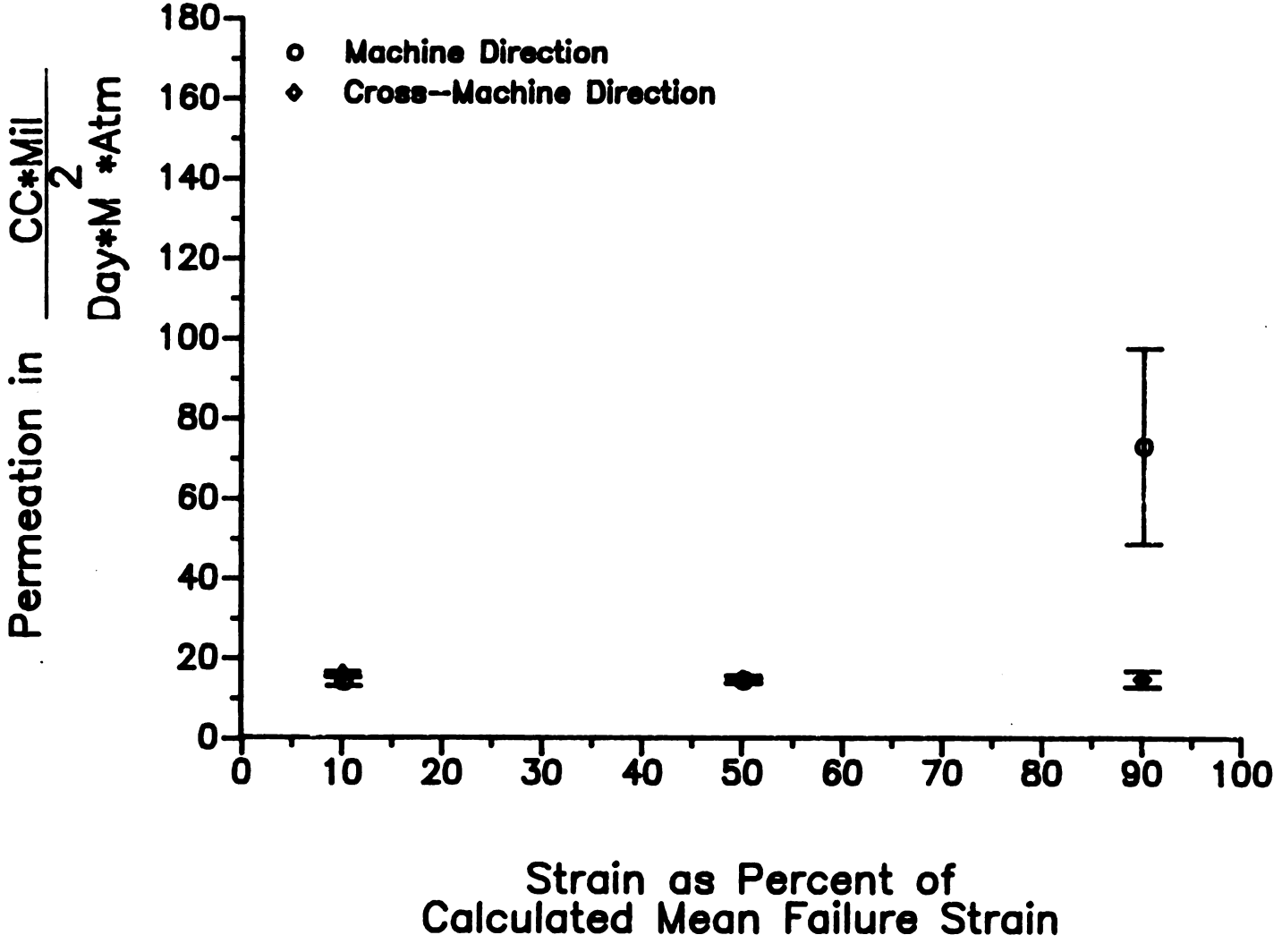

Figure 4. Graph of oxygen permeation rates versus orientation and strain at 1.0 in/min.

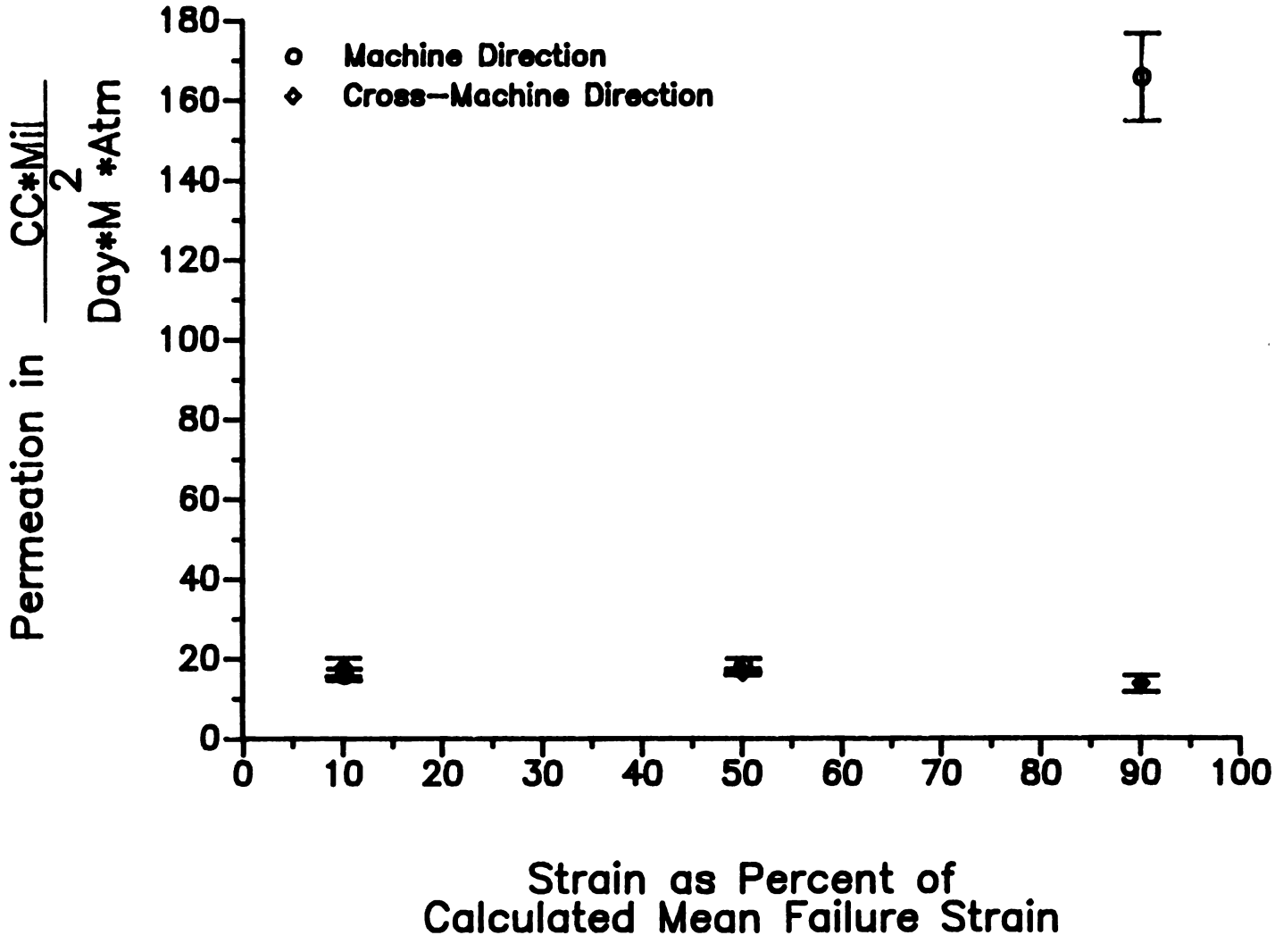

Figure 5. Graph of oxygen permeation rates versus orientation and strain at 10.0 in/min.

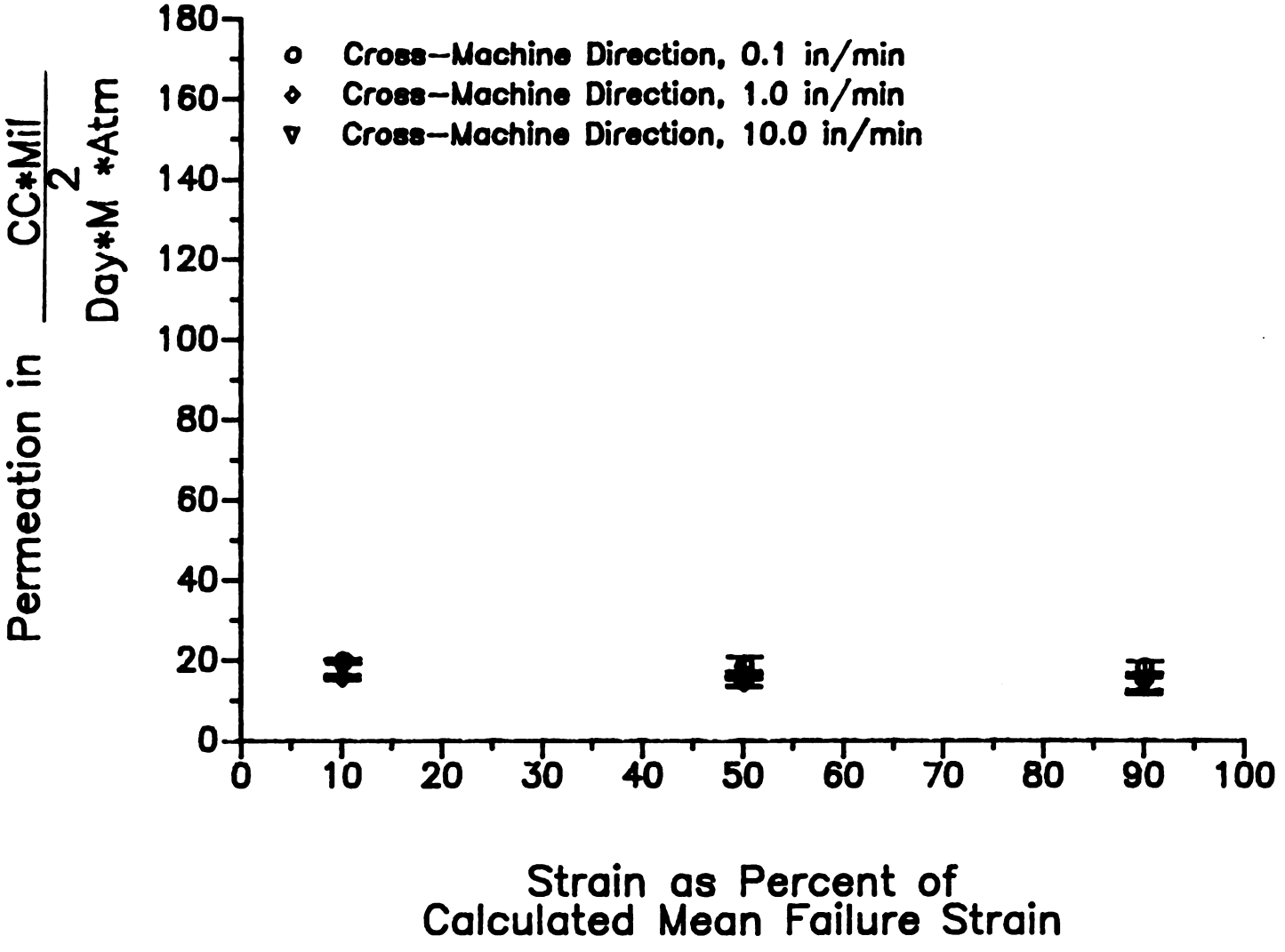

Figure 6. Graph of oxygen permeation rates versus strain and rate in the cross-machine direction.

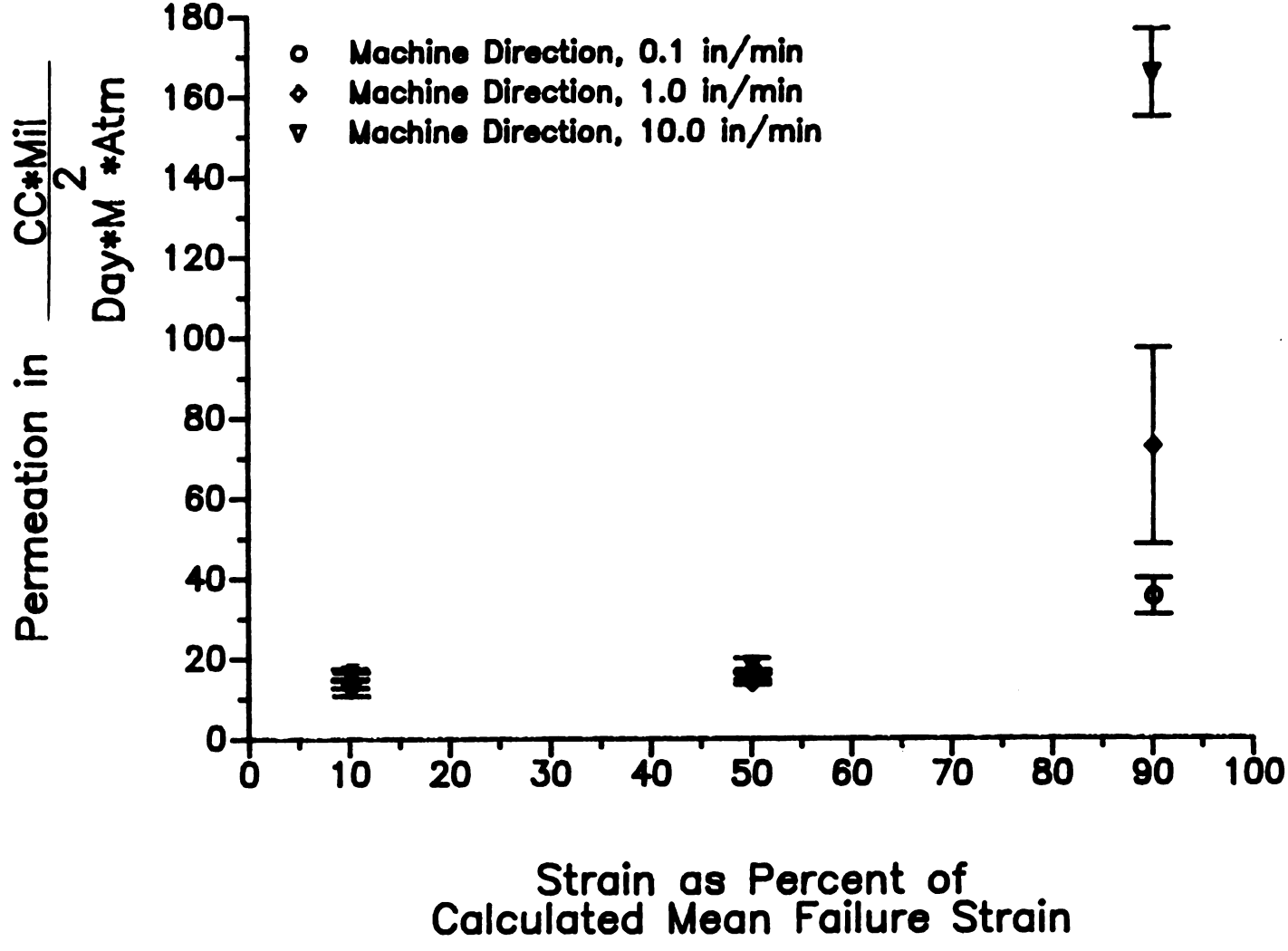

Figure 7. Graph of oxygen permeation rates versus strain and rate in the machine direction.

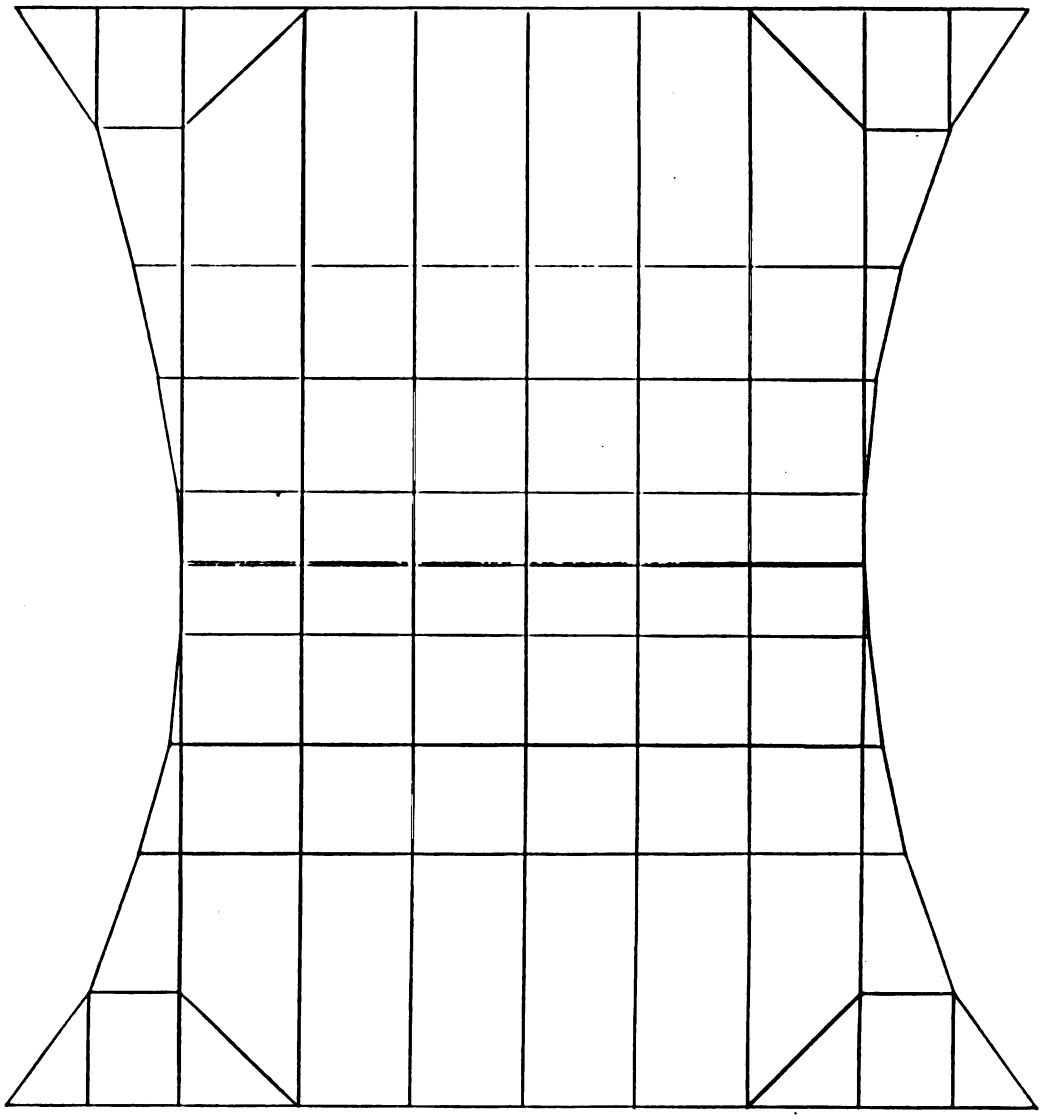

Figure 8. Diagram of finite-element grid for numerical analysis of strains in samples.

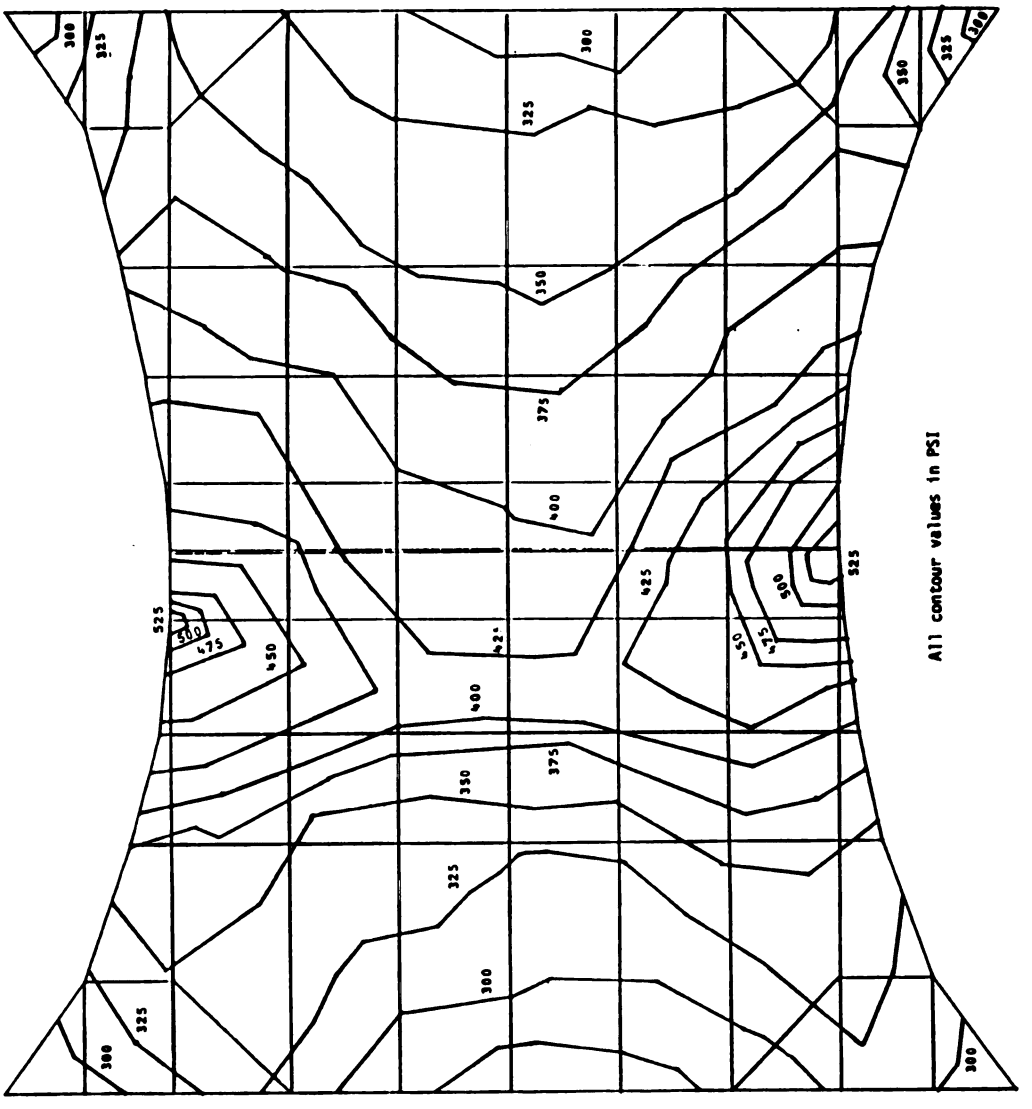

Figure 9. Plot of stress in isoparametric finite-element model.

RESULTS

The tabulated mean data from the experiment is presented in table 1, and shows some marked variation in permeation values. The values for most of the variations in strain rate, degree of strain, and material orientation are quite consistent, with the notable exception of the values for 90% of mean failure strain in the machine direction at all rates. Within those particular sample sets, the degree of increase of permeation increases with rising rates of strain. The degree of sample standard deviation for the data sets is fairly low, with the single exception of the values for permeation in the samples treated in the machine-direction, at 1.0 inches/minute, and 90% of mean failure strain.

Inspection of the graphed data (Figures 3,4,5) corroborates the notion that increased rates of permeation are related to specific combinations of strain rate, degree of strain, and material orientation. The largest increase is in the machine direction at high degrees of strain at all rates, but is apparently unchanging in the cross machine direction regardless of the other variables involved in the experiment (Figures 6,7).

An F-Test[15] was applied to the experimental data shown in Appendix A (Tables 8-14), with the results

Table 1. Tabulated Mean Permeation Data

Direction[1]	Rate[2]	Degree[3]	Mean Permeation Rate[4]	Sample Standard Deviation
XM	0.1	90%	18.332	1.540
		50%	18.810	2.211
		10%	19.767	0.550
""	1.0	90%	14.828	2.085
		50%	14.344	0.957
		10%	15.620	0.550
""	10.0	90%	15.752	1.265
		50%	16.577	0.732
		10%	17.853	1.914
MD	0.1	90%	35.420	3.762
		50%	16.573	0.490
		10%	13.640	3.042
""	1.0	90%	73.838	24.547
		50%	14.031	0.550
		10%	13.712	1.128
""	10.0	90%	165.781	11.044
		50%	14.031	0.550
		10%	15.956	1.485

[1]XM: Cross-machine direction
MD: Machine Direction

[2]Rate in inches/minute.

[3]Degree as a percentage of calculated mean failure extension (see appendix A).

[4]Permeation rate in $\left\{\frac{cc/mil}{day/M^2/Atm}\right\}$

summarized in Table 2. It is clear from the calculated F-values--all of which exceed the required values for significant effect--that all of the variables (both singly and in combination) to which the samples were subjected had a significant effect on the permeation rates through the samples. This relates well to the relationships between the strain variables and changes in permeation afforded by preliminary inspection of the data.

Further statistical analysis of the data, such as the establishment of a correlation coefficient between some particular strain variable, and the resultant change in permeation rates, would be hindered by the simplicity of the model used in determining the strain occurring within the deformed areas of the sample as well as the lack of data from a complete spectrum of strain and direction variables. Thus, although an approximate notion of the applied strain can be garnered from this experiment, and although the resulting significant shifts in the permeation can be experimentally obtained, a comprehensive quantitative relationship between the strain in the sample and changes in permeation requires the development of the stress-strain relationships occurring in an asymetrical composite system undergoing elastic and plastic deformation within a single sample--and is beyond the scope of this study.

Table 2. Statistical Summary

Source of Variation	DF	SS	MS	Obs. F	Required F Value 5%	Required F Value 1%
Total	53	12951.13				
Direction of Strain	1	1422.62	1422.36	179.14	4.11	7.17
Rate of Strain	2	813.62	406.62	51.21	3.26	5.06
Degree (%) of strain	2	3015.16	1507.61	198.88	3.26	5.06
Direction & Rate	2	969.76	484.88	61.06	3.26	5.06
Direction & Degree	2	3288.18	1644.12	207.07	3.26	5.06
Rate & Degree	4	717.15	179.30	22.58	2.63	3.72
Direction, Rate, & Degree	4	2439.47	609.80	78.85	2.63	3.72
Error	36	285.84	6.27			

CONCLUSIONS

In this study, samples of a single type of material were subjected to different, focused tensile strains and the resulting changes in oxygen transmission rates were measured and compared. The rate, degree, and direction of the applied strain, both singly and in combination, were shown to be significant factors in the breakdown of the barrier material. Analysis of the data showed that the tested material has incipient failure characteristics which render it capable of an order of magnitude increase in permeation--without rupturing the material or giving an immediate indication of having been damaged.

More specifically, the combination of strain in the machine-direction and a degree of strain at the 90% level (near the failure point of the material) seemed to afford the most significant change in permeation values. Further, permeation rates within these specific variables of strain increased in tandem with increasing rates of strain (Figure 6). The explanation of the specific causes of this behavior is difficult since the mechanisms of failure are, as previously described, quite complex and must take into account a plethora of interdependant variables. The simplest explanation for the behavior exhibited by this particular material would relate the permeation change to

the extensibility of the pouch material's polyester layer although there is no specific data to support this notion.

Ultimately, the best conclusion that can be drawn from this study is that there is a highly significant qualitative relationship between the variables of strain-rate, degree of strain, material orientation and a highly significant shift in oxygen permeation values. These shifts of permeation rates, in turn, represent a potential for the causation of quality loss in a product that depends on an intact oxygen barrier for quality maintenance. Additionally, a quantitative relationship might be attempted from the data garnered in this study but, as the specific amount of strain in all regions of each sample is not known in a simple experiment of this type any correlations might be misleading.

The utility of these types of studies lies in the development of methods for the analysis and design of high-barrier packages that can survive the mechanical stresses and strains inherent in their production and distribution. Predictive knowledge of the changes that can occur in a package will allow design of materials and structures that meet the needs of the package system without extensive "try it and see" prototyping that is both time-consuming and expensive.

A good correlation between permeation changes and strains in a packages' structure will allow the package

designer to utilize computer-based predictive models in the design process, as is done in other fields of engineering. The extension of the shelf-life and an increase in safety resulting from a more complete understanding of the necessary design factors should allow a more confident implementation of newer, more highly engineered types of packaging systems with a reduced pre-production lead time for prototyping and testing.

APPENDIX A

DATA ON THE PROPERTIES OF THE RETORT POUCH FILM USED IN THE PERMEATION STUDY.

TABLE 3: Tensile Failure Data.

Orientation: Cross-Machine Direction.

Rate of Strain: 10 in/min.

Sample	Extension at Failure
XM1	2.00 in.
XM2	2.50
XM3	3.00
XM4	2.07
XM5	3.13
XM6	2.69

Mean = 2.57 in.

Sample Standard Deviation: 0.467 in.

TABLE 4: Tensile Failure Data.

Orientation: Cross-Machine Direction.

Rate of Strain: 1.0 in/min.

Sample	Extension at Failure
XM7	2.80 in.
XM8	2.31
XM9	2.86
XM10	2.31
XM11	2.44
XM12	2.50

Mean: 2.50 in.

Sample Standard Deviation: 2.44 in.

TABLE 5: Tensile Failure Data.

Orientation: Cross-Machine Direction.

Rate of Strain: 0.1 in/min.

Sample	Extension at Failure
XM14	2.25
XM15	1.63
XM16	1.75
XM18	1.75
XM19	2.25
XM20	1.50

Mean: 1.85 in.

Sample Standard Deviation: 0.32 in.

TABLE 6: Tensile Failure Data.

Orientation: Machine Direction.

Rate of Strain: 10 in/min.

Sample	Extension at Failure
MD1	2.25
MD2	2.19
MD3	2.25
MD4	2.34
MD5	2.31
MD6	2.34

Mean: 2.28 in.

Sample Standard Deviation: 0.06 in.

TABLE 7: Tensile Failure Data.

Orientation: Machine Direction.

Rate of Strain: 1.0 in/min.

Sample	Extension at Failure
MD7	1.75 in
MD8	1.63
MD9	1.75
MD10	1.50
MD11	1.86
MD12	1.25

Mean: 1.62 in.

Sample Standard Deviation: 0.22 in.

TABLE 8: Tensile Failure Data.

Orientation: Machine Direction.

Rate of Strain: 0.1 in/min.

Sample	Extension at Failure
MD13	1.50
MD14	1.44
MD15	1.75
MD16	1.38
MD17	1.56
MD19	1.62

Mean: 1.54 in.

Sample Standard Deviation: 0.13 in.

Table 9. PERMEATION RATE DATA

Orientation: Cross-Machine Direction

Rate: 0.1 in/min

Calibration Value[2]: 17.390

Extension	Sample	Reading	Permeation	Mean & SD
90%	X20	0.21 mV	20.086[2]	
	X21	0.18	17.215	X=18.332
	X22	0.185	17.694	s=1.540
50%	X24	0.17	16.258	
	X25	0.21	20.086	X=18.810
	X26	0.21	20.086	s=2.211
10%	X27	0.20	19.129	
	X28	0.21	20.086	X=19.767
	X29	0.21	20.086	s=0.550

[1] Calibration values in CC/M²/Day/Mil/Atm per Millivolt. Taken from NBS-1470 Standard Polyester Film.

[2] Permeation in CC/M²/Day/Mil/Atm.

Table 10. PERMEATION RATE DATA

Orientation: Cross-Machine Direction

Rate: 1.0 in/min

Calibration Value[2]: 17.390

Extension	Sample	Reading	Permeation	Mean & SD
90%	X32	0.16mV	15.301[2]	
	X33	0.17	16.258	X=14.828
	X34	0.13	12.236	s=2.085
50%	X36	0.15	14.344	
	X37	0.16	15.301	X=14.344
	X38	0.14	13.393	s=0.957
10%	X39	0.17	16.258	
	X40	0.16	15.301	X=15.620
	X41	0.16	15.301	s=0.550

[1]Calibration values in CC/m²/Day/Mil/Atm per Millivolt. Taken from NBS-1470 Standard Polyester Film.

[2]Permeation in CC/M²/Day/Mil/Atm.

Table 11. PERMEATION RATE DATA

Orientation: Cross-Machine Direction

Rate: 10.0 in/min

Calibration Value[2]: 17.390

Extension	Sample	Reading	Permeation	Mean & SD
90%	X42	0.17mV	15.301[2]	
	X43	0.15	14.350	X=15.752
	X44	0.175	11.237	s=1.265
50%	X45	0.165	15.780	
	X37	0.18	17.215	X=16.577
	X38	0.175	16.737	s=0.732
10%	X39	0.16	15.301	
	X40	0.19	18.172	X=17.853
	X41	0.21	20.086	s=1.914

[1] Calibration values in CC/m²/Day/Mil/Atm per Millivolt. Taken from NBS-1470 Standard Polyester Film.

[2] Permeation in CC/M²/Day/Mil/Atm.

Table 12. PERMEATION RATE DATA

Orientation: Machine Direction

Rate: 0.1 in/min

Calibration Value[1]: 17.724

Extension	Sample	Reading	Permeation	Mean & SD
90%	M43	0.380mV	37.043[2]	
	M42	0.400	38.995	X=35.420
	M41	0.310	30.217	s=3.762
50%	M46	0.170	16.572	
	M45	0.165	16.082	X=16.573
	M44	0.175	17.061	s=0.490
10%	M50	0.165	16.082	
	M49	0.105	10.234	X=13.640
	M48	0.150	14.625	s=3.042

[1] Calibration values in CC/m²/Day/Mil/Atm per Millivolt. Taken from NBS-1470 Standard Polyester Film.

[2] Permeation in CC/M²/Day/Mil/Atm.

Table 13. PERMEATION RATE DATA

Orientation: Machine Direction

Rate: 1.0 in/min

Calibration Value[2]: 17.390

Extension	Sample	Reading	Permeation	Mean & SD
90%	M22	0.475mV	45.430[2]	
	M21	0.970	92.774	X=73.838
	M20	0.840	80.334	s=24.547
50%	M25	0.150	14.350	
	M24	0.150	14.350	X=14.031
	M23	0.140	13.393	s=0.550
10%	M28	0.150	14.350	
	M27	0.150	14.350	X=13.712
	M26	0.130	12.436	s=1.128

[1]Calibration values in CC/m²/Day/Mil/Atm per Millivolt. Taken from NBS-1470 Standard Polyester Film.

[2]Permeation in CC/M²/Day/Mil/Atm.

Table 14. PERMEATION RATE DATA

Orientation: Machine Direction

Rate: 10.0 in/min

Calibration Value[1]: 17.390

Extension	Sample	Reading	Permeation	Mean & SD
90%	M32	1.800mV	172.161[2]	
	M31	31.302	172.161	X=165.781
	M30	27.824	153.032	s=11.044
50%	M35	0.170	16.258	
	M34	0.205	19.608	X=14.031
	M33	0.200	19.129	s=0.550
10%	M38	0.150	14.350	
	M37	0.170	16.258	X=15.956
	M36	0.180	17.270	s=1.485

[1]Calibration values in CC/m²/Day/Mil/Atm per Millivolt. Taken from NBS-1470 Standard Polyester Film.

[2]Permeation in CC/M²/Day/Mil/Atm.

APPENDIX B

DETERMINATION OF THE MECHANICAL PROPERTIES OF THE FILM USED IN THE NUMERICAL MODEL

Determination of Poisson's ratio.

Poisson's ratio is the ratio of lateral strain to axial strain[16]. For the purposes of this study, a simple determination is sufficient for use in the numerical model. Sample strips of retort pouch material 1" x 10" were stretched 1" in an Instron Tensile Tester (Model #1116) and the change in the width of the sample was recorded. Orientation was found not to be a factor, and thinning effects were not considered. The value of 0.42 is similar to nylon, and is in the right range for materials of this type[17].

Table 15. Data used for the determination of Poisson's ratio.

Sample	Orientation	Lateral Strain
1	Cross Machine Direction	0.04
2	"	0.04
3	"	0.04
4	"	0.04
5	"	0.06
6	Machine Direction	0.02
7	"	0.04
8	"	0.06
9	"	0.04
10	"	0.04

Mean Lateral Strain: 0.042

Sample Standard Deviation: 0.011

Axial Strain: 1"/10"=0.1

Poisson's Ratio=Lateral Strain/Axial Strain

=(0.042)/(0.1)=0.42

Determination of the Modulus of Elasticity.

The modulus of elasticity (E) is the ratio of applied load to resultant deflection, and is usually determined to be the slope of a stress-strain curve in the linearly elastic portion of the curve[14]. For the purposes of the numerical simulation, a simple determination of E is sufficient.

Ten samples (five from each orientation) were placed under tensile stress (rate=1.0 in/min), and the slope of each curve's elastic region was determined, giving the coefficient of elasticity.

Table 16. Calculation of the Modulus of Elasticity.

In this case all of the sample's slopes were identical within the limits of the recording device attached to the tensile tester.

Number of Samples: 10 (5 from each orientation)
Sample width: 1.0 in.
Load: 13.3 lbs.
Thickness: 0.052 in.
Measured strain: (0.1 in./8.333 in.)= 0.012

$$E = \frac{(\text{Load/Thickness})}{(\text{Measured Strain})} = 2.137 \times 10^6 \text{ psi.}$$

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