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STRENGTH VARIATIONS OF BILATERALLY ORIENTED RUBBER HYDROCHLORIDE FILM

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
Roland Keith Lancaster

1957

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STRENGTH VARIATIONS OF BILATERALLY ORIENTED RUBBER HYDROCHLORIDE FILM

By

ROLAND KEITH LANCASTER

AN ABSTRACT

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Forest Products

1957

Approved: James W. Goff

During preliminary investigation of the strength properties of bilaterally oriented rubber hydrochloride film considerable variation was found in breaking factor values for samples selected from different sections of the same film. The purpose of this paper is to present the methods used to isolate the areas of various strengths and on the basis of strength measurements to present a probable explanation of this variation based on the molecular structure and organization of the film.

Because of the crystalline nature of rubber hydrochloride and the transparency of the film used, optical examination using polarized light proved most fruitful. By the use of the polariscope, it was possible not only to determine the principal direction of orientation but also to make a semi-quantitative estimate of the extent of orientation.

On the basis of work carried out with similar polymeric materials an interpretation of the patterns of birefringent areas visible in the polariscope was made. It would be expected that the strength measured with the direction of orientation would be greater than that measured across the direction of orientation. It would likewise be expected that the per cent difference between the "with" and "across" strength measurements would be greater for the highly oriented areas than the corresponding strength measurements for very slightly oriented areas.

To confirm these observations samples were selected for strength measurements by polariscopic inspection. Breaking factor, thickness, and elongation measurements were then made on these samples. The results of these determinations indicated that the original interpretations of the polariscopic patterns were correct.

The principal value of this study is that it provides a foundation for further work with this film inasmuch as it furnishes a method for selecting homogeneous samples. In addition the optical inspection procedure offers possibilities as a simple and rapid technique for evaluating the effect of changes in the orientation process.

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Sincere thanks are likewise extended to Tee-Pak, Incorporated, of Chicago, Illinois, for their generosity in supplying the film used in this study.

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I. INTRODUCTION

This study represents the initial investigation in this laboratory of bilaterally oriented rubber hydrochloride film.[1] The original objective of this investigation was to measure any changes in strength properties which might occur when this film was subjected to controlled shrinkage at elevated temperatures. It was found, however, that there was a large variation in the breaking factor (2) values of samples selected from different sections of the same film, and for this reason it was deemed advisable to shift the emphasis of the project to a study of this variation in strength.

The purpose of this paper is to present the methods used to isolate the areas of various strengths and, on the basis of strength measurements, to present a probable explanation of this variation based on the molecular structure and organization of the film.

Because of the crystalline nature of rubber hydrochloride and the transparency of the film used, optical examination using polarized light proved most fruitful. By the use of the polariscope, it was possible not only to determine the principal direction of orientation but also to make a semi-quantitative extimate of the extent of

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[1] This film is available under the trade name of "Snug-Pak" from Tee-Pak, Inc., Chicago, Illinois.

orientation. Breaking strength measurements which were made on samples selected by polariscopic inspection were used to confirm the optical observations.

II. PREVIOUS WORK

Crystallization and Orientation of High Polymers

Because of the general familiarity with inorganic crystalline materials, it is often inferred that for a substance to be classified as crystalline it must exhibit symmetrical plane boundaries. This property is in reality merely an external manifestation of a high degree of internal geometrical organization. It is possible for a material to possess this high degree of internal organization without these external features. Such is the case with many high polymers; for, although they do not exhibit plane boundaries and sharp edges, they do show many properties of normal crystals such as well defined x-ray patterns, birefringence, and anisotropy of some mechanical and physiochemical properties (8). In this study the birefringence and anisotropy of mechanical properties will be of particular interest.

Alfrey (1) defines a crystalline region as a section of matter in which the structural units are arranged in a far-reaching regular pattern. In the case of inorganic crystals the structural units are usually atoms or ions; however, this must be expanded to include repeating molecular segments in the case of high polymers.

It must also be recognized that even in nonpolymeric crystals the arrangement is never completely perfect, but the imperfections are almost always of a local nature. The significant point is that these small irregularities do not destroy the long range over-all regularity of arrangement. This distinction is especially important when dealing with polymeric crystals where local differences are common.

The size of these polymeric crystals may range from 50 to 10,000 Angstrom units (8). However, Alfrey (1) points out that the essential requisite is that they be large enough to produce a distinct x-ray pattern.

Mark (8) sums up his discussion of crystallites by defining them as small areas of somewhat indefinite size and shape inside of which the monomeric units are arranged in a three-dimensional periodic pattern.

One of the most distinguishing characteristics of polymeric crystalline materials is that they are never completely crystalline. Regions of high geometric order, called crystallites or micelles, are separated by relatively amorphous regions (9) (10). Because of the large size of the polymer molecule and the fact that the crystallites are made up of regularly arranged molecular segments, one molecule usually extends through several phases. At various locations along its length one molecule may participate in several different crystalline and amorphous regions (10).

Another factor to be considered is the orientation of the crystallites in the polymer. Usually these crystalline areas are randomly oriented; however, by subjecting the polymer to special treatment such as stretching, the crystallites may become aligned in one direction.

Birefringence in High Polymeric Materials

Refraction of light is best accounted for by realizing that light is an electromagnetic phenomenon and as such an interaction between its electric field and the field of the electrons in the material through which it passes is to be expected. The extent of this interaction is dependent upon the density and polarizability of the material, and the net result is a slowing down of the light through the material. This phenomenon is referred to as refraction. If a material presents a greater density in one direction than in another, two different refractive indices will result. This property of birefringence is characteristic of many crystalline materials. Both Houwink (7) and Alfrey (1) present a more rigid theoretical discussion of birefringence.

The crystalline regions of polymers exhibit this property of birefringence; and, if sufficiently large crystallites are present, they may be conveniently studied with the polarizing microscope. When such a berefringent material is placed between the crossed Nicol prisms of the microscope, it resolves the plane polarized light produced by the polarizer into two perpendicular components propagated at different velocities to produce a certain optical path difference. Only the components of these two perpendicular waves which are vibrating in the plane of the analyzer will be transmitted by it. At this point interference occurs because of the optical path difference (7). The extent of this interference is determined by the two different propagation velocities and, therefore, provides an index of the extent of crystallization.

Another type of birefringence can occur in polymers and this is known as orientation birefringence. It is based on an assymetric arrangement of molecules not caused by crystallization. This type of birefringence occurs in polymers when chainlike molecules are elongated or stretched and become parallel thus producing an unequal distribution of density in different directions. According to Houwink (7) this type of birefringence provides a measure of the orientation and is not related to crystallization effects.

Anisotropy of Mechanical Properties

It is generally agreed that both crystallization and orientation produce a marked increase in the tensile strength of a polymeric material. This increase is always noted in the direction of alignment of the molecules (1)(7)(9).

In the case of orientation of chainlike molecules they may become extended to the most favorable position for the exertion of maximum secondary valence forces between adjacent chains. Although the strength of a single secondary bond is quite small, the combined strength of all the secondary bonds along the entire chain length becomes a major factor in determining the strength of the material. From this Houwink (7) concludes that for a break to occur in an oriented nonplastic material many strong primary bonds must be broken.

Crystallization which may result from such orientation produces an even greater increase in tensile strength because the relatively high crystal energies make sliding of the molecules past one another virtually impossible. A break may occur in this case only by the rupture of strong primary bonds.

The question of the relative importance of orientation and crystallization in determining tensile strength has been investigated by several workers for the case of natural rubber, and their results are summarized by Alfrey (1). They found that orientation was the most important single factor in determining tensile strength. Their study showed that oriented noncrystalline rubber was stronger than both crystallized nonoriented and noncrystallized nonoriented rubber. Oriented crystalline rubber proved to be the strongest of all.

Crystallization and Orientation of Rubber Hydrochloride

Rubber hydrochloride is formed by the treatment of natural rubber with dry hydrogen chloride and according to Bunn (4) crystallizes spontaneously without a stretching treatment. Bunn (3) also states that upon stretching a fiber type x-ray diagram is produced which suggests that an orientation of the crystallites has taken place. From x-ray diagrams Bunn (4) has also worked out the size, shape, and composition of the crystal unit cell.

III. EXPERIMENTAL PROCEDURE

Introduction

Although there appeared to be no published account of optical examination of rubber hydrochloride, the results obtained with thin rubber films suggested that such an approach might yield information concerning the crystallinity and orientation of the film. Examination was therefore made using both the polariscope and the polarizing microscope. The patterns which appeared when the film samples were placed between crossed Polaroid sheets indicated that the degree of birefringence varied markedly from one area to another. The problem then became one of trying to relate the variations in birefringence to the variation in breaking strength.

Film Tested

The film used in this study is a commercial packaging film produced by stretching a rubber hydrochloride film approximately 100 per cent both longitudinally and across the web. This stretching process is carried out at temperatures slightly below the melting point of rubber hydrochloride. The film is cooled while in the stretched state, and it maintains these extended dimensions as long as the temperature of the film is kept below the point at which

flow begins to take place.

Samples of the rubber hydrochloride film which had not been stretched were also examined.

Optical Examination

The principal optical inspection was carried out using the General Radio Company polariscope shown in Figure 1. The polariscopic observations were made in a completely darkened room so that the patterns would be more readily visible.

Figure 2 shows some of the typical patterns which were observed when samples of the stretched film were placed between crossed Polaroids. On the basis of theoretical considerations the light areas were interpreted as being highly birefringent. Conversely the darker areas were considered to be only very slightly birefringent. The striation effect shown was interpreted as giving an indication of the general direction of orientation of the assymetric units in the film responsible for the birefringence as well as indicating a nonhomogeneity of orientation. For example Figures 2-1 and 2-2 show highly oriented areas with the principal direction of orientation horizontal or normal to the machine direction, while Figures 2-3, 2-4, and 2-5 show highly oriented areas with the orientation direction vertical or parallel to the machine direction. Figures 2-6 and 2-7 show both horizontal and vertical orientation in adjacent areas. In Figures 2-8, 2-9, and 2-10 several dark areas are visible which were typical of the very slightly oriented sections. Figure 2-11 shows an interesting anomalous checkered pattern. In all cases the machine direction is vertical. Although it is not readily apparent from the photographs shown in Figure 2, faint striations were also present in the dark areas which gave an indication of the direction of the slight amount of orientation which was present.

When the film which had not been subjected to the stretching process was placed between the crossed Polaroids, a completely dark field was produced indicating the absence of any birefringence in the film. This was true at all possible positions of rotation of the film in the field.

Microscopic examination of the film was made using a Leitz petrographic microscope and an American Optical Spencer stereoscopic polarizing microscope. The stretched film when magnified showed microscopic patterns which were very similar to the macroscopic patterns which appeared in the polariscope. Although various areas could be isolated which appeared to be principally either birefringent or isotropic, striations were present which suggested that even on the microscopic scale the film was far from homogeneous. The nonstretched film was also examined using magnifications

Figure 1. General Radio Company Type 1534-A Polariscope with a DuMont Type 302 Oscillographic Record Camera.

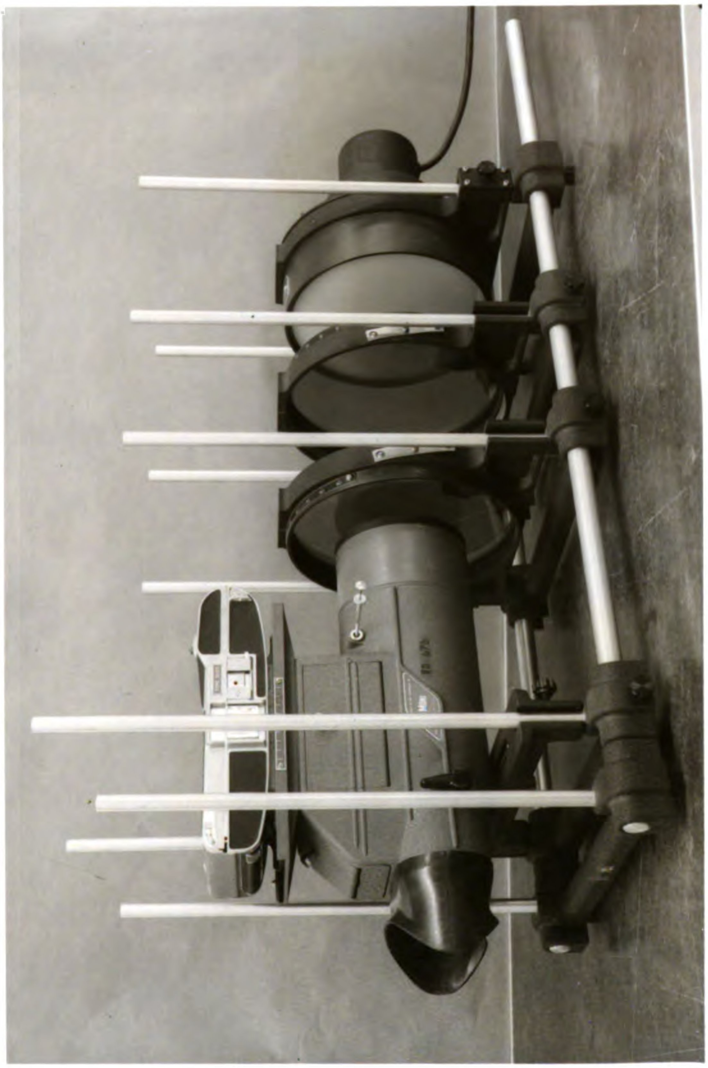
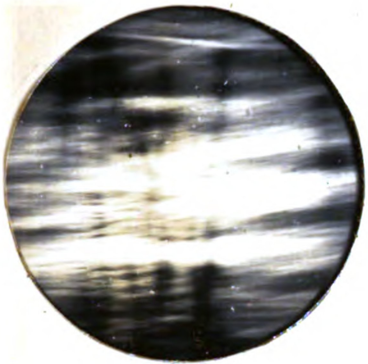
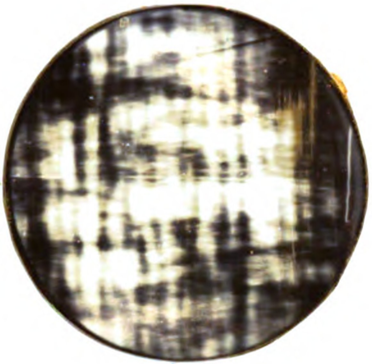


Figure 2. Polariscopic patterns obtained by placing samples of film D between crossed Polaroids. Note the one inch reference marks on 2-8 and 2-10.



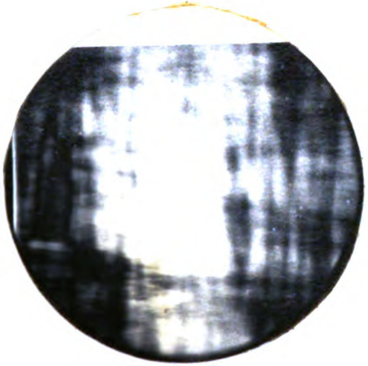
2-1

2-2



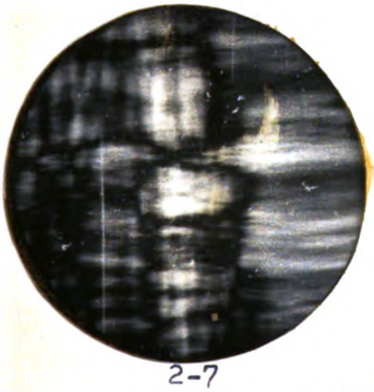
2-3

2-4



2-5

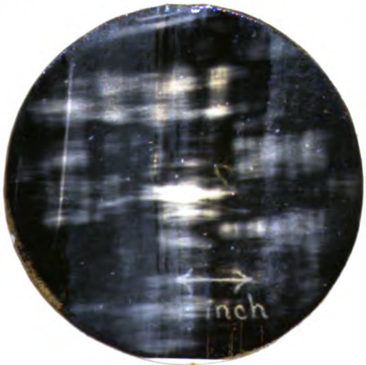
2-6



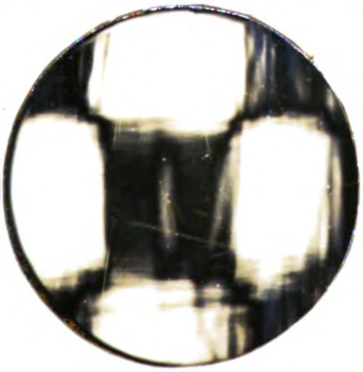
2-7

2-8

2-9



2-10



2-11

of up to 360 diameters, and no indication of birefringence was noted. This would indicate that the crystallites which Bunn (4) states should be present were extremely small. In the case of natural rubber Smith and Saylor (11) were able to prepare crystals which were large enough to be plainly visible in the polarizing microscope using a magnification of 250 diameters.

Selection of Samples

In the selection of samples to be used for strength measurements, four categories of orientation relationships were recognized; these were:

(1) highly oriented areas with the principal direction of orientation parallel to the machine direction;

(2) highly oriented areas with the principal direction of orientation normal to the machine direction;

(3) slightly oriented areas with the principal direction of orientation parallel to the machine direction; and

(4) slightly oriented areas with the principal direction of orientation normal to the machine direction.

In each of these categories twelve samples were taken with the sample length parallel to the direction of orientation, and twelve samples were selected with the sample length normal to the direction of orientation. Sample length is used here as that direction in which the tension is applied during the breaking strength test.

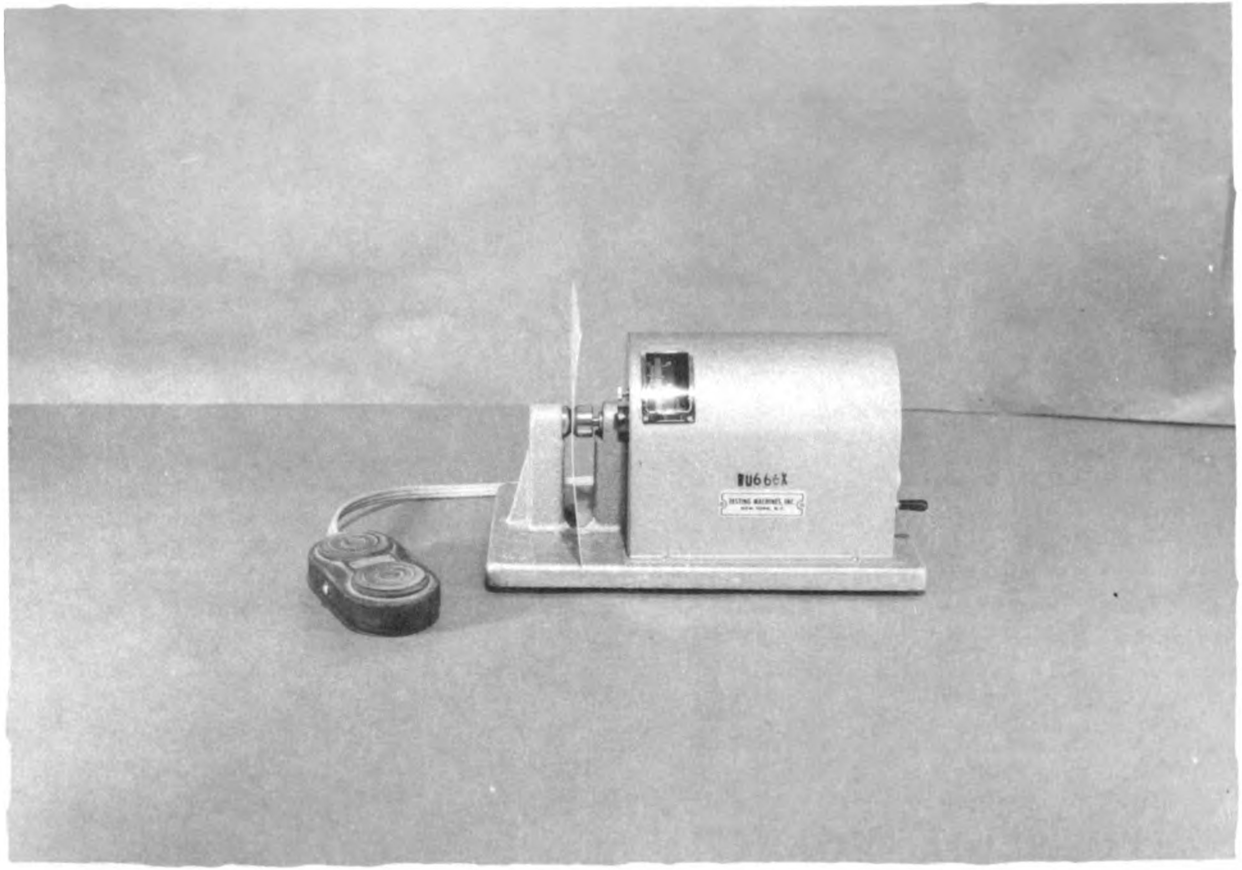
The actual technique used in selecting the samples simply involved placing the film between crossed Polaroids and marking and coding the appropriate areas of the film with a wax marking pencil. One inch wide samples were then cut from the marked areas using a Thwing Albert Model JDC 25 Precision Sample Cutter.

The thickness of each sample was measured using the Testing Machines, Incorporated, Model 555 Motor Driven Micrometer shown in Figure 3. Three thickness measurements were made across the one inch dimension of each sample. Since the anvils of the micrometer have a diameter of approximately .6 of an inch, these measurements represent considerable overlap. The length of sample actually subjected to tension in the testing machine was only one-half inch, thus the thickness measurements covered virtually the entire sample. Because these measurements involved readings which approached the limit of accuracy of the micrometer, the zero point of the instrument was checked carefully both before and after each reading. The thickness value was rejected if the zero point had drifted more than .00002 of an inch. The micrometer was adjusted so that the anvils exerted a pressure of eight pounds per square inch on the sample.

Measurement of Tensile Properties

In so far as possible these tests were carried out

Figure 3. Testing Machines, Incorporated, Model 555 Motor Driven Micrometer.


TESTING MACHINES, INC.
NEW YORK, N.Y.

according to the "Tentative Methods of Tests for Tensile Properties of Thin Plastic Sheets and Films" of the American Society for Testing Materials (2). The Schopper type testing machine shown in Figure 4 was used in accordance with Method B of the above procedure with two exceptions. First, the maximum rate of motion of the powered grips of this testing machine was twelve inches per minute as opposed to the recommended twenty inches per minute. Second, the recommended initial grip separation was two inches; however, because of the limit of the size of some of the oriented areas, it was necessary to use an initial grip separation of one-half inch.

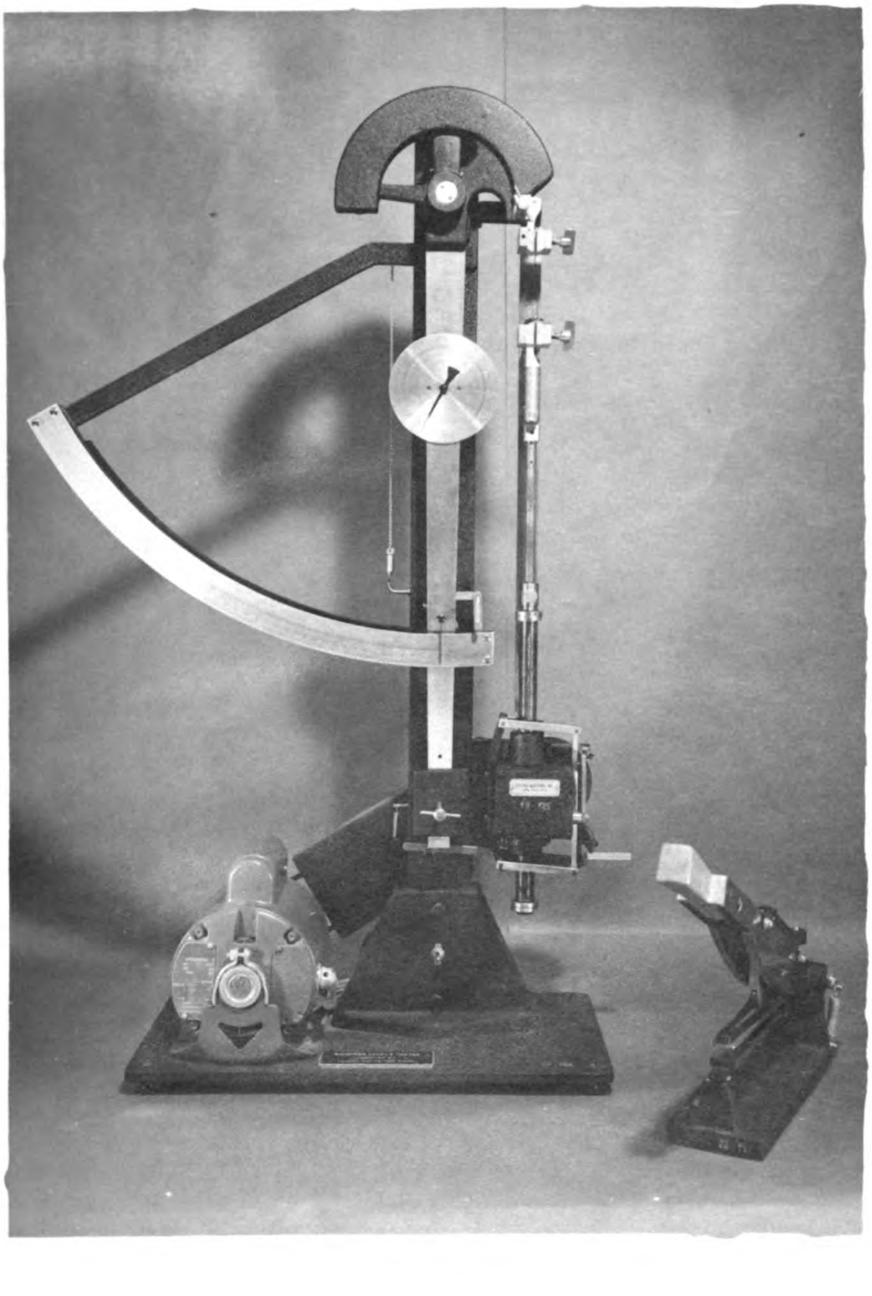
To avoid sample slippage in the jaws each jaw face was covered with a coarse cloth backed pressure sensitive tape.

The testing machine used also provided a direct measure of the elongation of each sample at break.

The calibration of the testing machine was checked initially and several times during the tests. This was carried out by attaching weights of known value to the upper jaws and checking the value indicated by the pendulum. The values corresponded within the limits of possible error of reading the instrument.

The results of these strength measurements were expressed as breaking factors. The breaking factor is

Figure 4. Schopper Tensile Testing Machine and Thwing Albert Model JDC 25 Sample Cutter.



defined as the breaking load divided by the original width of the test specimen (2). Because of the design of the testing machine, the breaking factor is based on the maximum strength which is not necessarily the strength at break.

All tests in this study were carried out in the standard laboratory atmosphere of 73.4 ± 2^{o} Fahrenheit and 50 ± 2 per cent relative humidity (2).

Three types of film were included in this study. They are coded B, D, and E. Film B is the nonstretched Pliofilm of type N2 which is described by the producer (6) as a "standard all-purpose, low water-vapor-gas transmission packaging film." Film D is produced by laminating two sheets of 80 gauge[2] N2 Pliofilm and then subjecting it to the orientation process. Film E is formed in a similar manner from one sheet of 80 gauge and one sheet of 120 gauge N2 Pliofilm.

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[2] A method of indicating the thickness of a film in which the numerical prefix is the last figures of the 5-digit decimal fraction of the thickness in inches, thus: 80 gauge = .00080 inches. This method of expressing thickness is used for most packaging films except Cellophane.

IV. ANALYSIS OF DATA

The original observations of the gauge, breaking factor, and elongation for all three films are recorded in Tables I through IX of the appendix. Tables X through XVII of the appendix summarize the statistical analyses of these data. In this connection it should be pointed out that the significance of differences between mean breaking factors and mean thicknesses was determined by the use of the "least significant difference between means" technique described by Snedecor (12). The LSD values listed in these tables are the smallest differences between any two means which may exist if the two means are to be interpreted as being significantly different at the specified level.

Since the existance of equality of variance is one of the assumptions of the analysis of variance technique, it is necessary to check this assumption for each set of observations (3). This is carried out in Tables XIV through XVII of the appendix by a method discussed by Snedecor (12).

The significance of the difference between the mean breaking factors of film B is shown in Table IX of the appendix. In this case it was necessary to modify the number of degrees of freedom available for the "t" test since the variances of the "with" and "across" strengths were not the same. The technique used is presented by Dixon and Massey (5).

Table I below summarizes the breaking factor and gauge measurements with respect to orientation and machine direction. In all cases except observations (7) and (8) of film D the breaking factor measured with the direction of orientation was significantly larger than the breaking factor measured across the direction of orientation at a level of at least 5 per cent. In all cases except observations (5) and (6) of film E it was found that there was no significant difference between the gauge measurements of the "with" and "across" samples.

Table II presents the results of a calculation of the per cent difference in breaking factors as measured with and across the direction of orientation. These figures were calculated by dividing the difference between the "with" and the "across" by the "with" and expressing the result as a percentage.

Tables XVIII and XIX of the appendix represent strength values of samples of films B and E which were measured on a Baldwin Emery Model SR4 Testing Machine. These values are included because with this testing machine it is possible to measure both the strength at yield and break. There was no difference between the yield and break values noted for film E. A significant difference between the break and yield strengths was apparent for film B. These data are not directly comparable to that reported in Tables I through IX of the appendix since with this testing machine it was necessary to employ Method A as recommended by the American Society for Testing Materials (2). These tables are included merely to indicate the difference in strength at yield and break for the nonstretched film.

TABLE I

A SUMMARY OF STRENGTH AND GAUGE MEASUREMENTS

Film	Extent of Orientation	Direction of Sampling	Orientation Parallel to Machine Direction			Orientation Normal to Machine Direction		
			Obs.	Breaking Factor lbs./in.	Gauge	Obs.	Breaking Factor lbs./in.	Gauge
E	Highly Oriented	With	(1)	3.74	42.7	(3)	2.73	28.9
		Across	(2)	2.33	44.6	(4)	1.70	28.4
	Slightly Oriented	With	(5)	3.03	33.0	(7)	2.17	31.5
		Across	(6)	2.48	44.5	(8)	1.92	33.9
D	Highly Oriented	With	(1)	4.51	49.0	(3)	4.23	50.4
		Across	(2)	2.51	50.9	(4)	2.55	52.1
	Slightly Oriented	With	(5)	2.49	38.4	(7)	2.01	36.2
		Across	(6)	2.06	38.6	(8)	1.82	41.8
B	Slightly Oriented	With	(1)	6.54	122.9			
		Across	(2)	5.95	127.0			

TABLE II

PER CENT DIFFERENCE IN STRENGTH AS MEASURED WITH AND ACROSS THE ORIENTATION DIRECTION

Film	Extent of Orientation	Orientation Parallel to Machine Direction	Orientation Normal to Machine Direction
E	Highly Oriented	37.70 %	37.73 %
	Slightly Oriented	18.15 %	11.52 %
D	Highly Oriented	44.35 %	39.72 %
	Slightly Oriented	17.26 %	9.45 %
B	Slightly Oriented	9.02 %	

V. CONCLUSIONS AND DISCUSSION

The most obvious conclusion which might be drawn from an examination of the data of Table I is that the strength measured with the direction of orientation is greater than that measured across the direction of orientation. This conclusion has value in that it tends to confirm the original hypothesis that the patterns observed in the polariscope are produced by an orientation phenomenon. From the work of Bunn (4) it seems likely that this consists of an orientation of crystallites.

Another indication of the validity of the assumptions concerning the patterns observed in the polariscope may be found in Table II. If the areas selected as being highly and slightly oriented are actually oriented to the degree indicated, then it would be expected that the per cent difference in strength between the "with" and "across" directions for a highly oriented area would be significantly larger than the corresponding difference for a slightly oriented area. This was found to be the case as shown in Table II.

It should be noted that a slight anisotropy of strength was found in the nonstretched sample also. It is possible that this likewise was caused by an orientation of crystallites, but that the aggregates of crystallites were too small to exhibit a visible optical effect. If it is assumed that this anisotropy of strength of the nonstretched film is actually caused by an orientation in the machine direction, then the per cent difference in strength measured in the "with" and the "across" directions for the nonstretched film is approximately the same as the per cent difference found for the very slightly oriented areas of the stretched film.

The original question concerning the source of the strength variability of the stretched film remains to be answered. The results of this study indicate that it is influenced by both thickness and orientation. For example, in film E, if samples parallel to the machine direction had been selected without the aid of the polariscope, observations (1), (4), (5), and (8) would have been typical values (see Table I). Of these, observations (4), (5), and (8) are essentially the same thickness. The strength differences noted could logically be assigned to orientation effects. Similarly, since observations (2), (6), (4), and (8) of film E represent samples selected across the orientation direction, it would be expected that their strength values would exhibit no orientation effects. This is true when comparisons are made between (2) and (6) and between (4) and (8). These two comparisons are not complicated by differences in thickness. However, when (2) and (4) are compared and (6) and (8) are compared, the significant differences noted can be accounted for only by the differences in thickness. Similar relationships were found for film D.

Although further study would be necessary to clarify the relationship between the degree of orientation and the thickness, these data suggest that within limits they may be considered to be independent variables.

The principal value of this study is that it provides a foundation for further experimentation. For example, it would now be possible to proceed with the original objective which was to measure strength changes upon heat shrinkage. It would be possible now to select uniform samples for such a study. In addition the optical inspection procedure offers possibilities as a simple and rapid technique for evaluating the effect of changes in the orientation process.

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APPENDIX

TABLE I
FILM D
HIGHLY ORIENTED AREAS
ORIENTATION PARALLEL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
35,30,36	33.7	4.40	.500	46,35,43	41.3	2.25	.292
55,61,60	58.7	4.22	.362	51,60,59	56.7	2.62	.402
53,50,47	50.0	4.90	.545	45,44,45	44.7	2.18	.380
56,57,54	55.7	5.18	.614	40,42,40	40.7	2.15	.380
44,36,41	40.3	3.35	.419	45,46,50	47.0	2.30	.200
55,54,40	49.7	4.98	.548	39,41,43	41.0	2.05	.340
50,51,54	51.7	4.80	.612	45,50,50	48.3	2.25	.260
48,50,41	46.3	4.72	.442	54,52,53	53.0	2.64	.318
48,47,48	47.7	5.54	.564	50,50,48	49.3	2.34	.336
52,53,52	52.3	4.00	.375	56,57,53	55.3	2.87	.430
47,45,50	47.3	4.00	.340	58,58,60	58.7	2.84	.586
54,51,58	54.3	3.98	.332	72,80,74	75.3	3.62	.986
Mean	49.0	4.51	.471		50.9	2.51	.407

TABLE II
FILM D
HIGHLY ORIENTED AREAS
ORIENTATION NORMAL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
64,61,61	62.0	4.85	.504	41,40,37	39.3	2.10	.286
38,43,45	42.0	3.38	.400	41,37,40	39.3	2.05	.230
49,49,53	50.3	4.05	.544	65,70,77	70.7	3.32	1.070
51,53,52	52.0	5.68	.710	55,54,55	54.7	2.50	.740
67,52,45	54.7	4.22	.292	73,72,68	71.0	3.38	.530
74,45,48	55.7	3.66	.348	68,65,63	65.3	3.12	.466
53,37,33	41.0	3.30	.342	35,42,43	40.0	2.24	.260
68,60,52	60.0	4.40	.380	43,42,46	43.7	2.00	.348
54,51,48	51.0	4.60	.648	50,46,52	49.3	2.55	.378
44,44,49	45.7	4.38	.540	53,59,60	57.3	2.55	.485
50,35,32	39.0	2.74	.282	59,60,59	59.3	2.85	.382
55,52,47	51.3	5.44	.617	33,35,38	35.3	1.90	.320
Mean	50.4	4.23	.422		52.1	2.55	.458

TABLE III
FILM D
SLIGHTLY ORIENTED AREAS
ORIENTATION PARALLEL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
40,35,41	38.7	3.10	.392	35,31,34	33.3	1.96	.265
58,54,52	54.7	2.64	.352	41,35,45	40.3	1.26	.198
37,35,30	34.0	2.56	.352	30,28,51	36.3	1.75	.188
32,32,31	31.7	2.80	.325	47,40,40	42.3	2.00	.276
31,34,35	33.3	2.24	.284	35,42,40	39.0	2.38	.385
50,77,68	65.0	2.15	.265	41,37,45	41.0	2.22	.340
37,33,30	33.3	1.64	.240	36,35,36	35.7	1.95	.200
33,24,22	26.3	1.86	.236	32,39,37	36.0	2.20	.225
36,34,35	35.0	2.60	.359	42,41,40	41.0	2.35	.350
32,37,35	34.7	2.40	.299	32,30,33	31.7	2.24	.328
37,29,36	34.0	2.55	.348	54,60,35	49.7	2.00	.290
40,40,40	40.0	3.30	.434	43,33,36	37.3	2.35	.355
Mean	38.4	2.49	.324		38.6	2.06	.283

TABLE IV
FILM D
SLIGHTLY ORIENTED AREAS
ORIENTATION NORMAL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
28,40,43	37.0	1.68	.222	42,40,40	40.7	1.98	.304
32,31,26	29.7	2.18	.278	36,33,33	34.0	1.92	.345
31,27,27	29.3	1.90	.258	46,55,50	50.3	1.62	.225
31,24,54	36.3	1.70	.250	39,26,27	30.7	1.46	.250
36,32,34	34.0	2.35	.325	42,37,41	40.0	2.40	.428
26,38,37	33.7	1.88	.270	43,32,32	35.7	1.80	.300
54,33,32	39.7	2.15	.320	43,60,63	55.3	1.56	.292
36,50,43	43.0	1.82	.222	38,40,41	39.7	2.95	.486
54,32,41	42.3	1.90	.256	60,65,48	57.7	1.38	.275
37,32,35	34.7	2.42	.330	34,25,48	35.7	1.48	.248
37,37,35	36.3	2.10	.258	33,30,52	38.3	1.55	.262
45,37,32	38.0	2.02	.272	47,50,33	43.3	1.68	.290
Mean	36.2	2.01	.272		41.8	1.82	.309

TABLE V
FILM E
HIGHLY ORIENTED AREAS
ORIENTATION PARALLEL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
37,40,37	38.0	3.66	.340	43,45,57	48.3	2.40	.200
46,45,45	45.3	3.75	.488	48,44,41	44.3	2.20	.110
50,45,46	47.0	3.65	.502	50,44,43	45.7	2.30	.148
40,35,37	37.3	3.55	.350	42,38,37	39.0	1.95	.136
37,35,33	35.0	3.78	.330	54,47,46	49.0	2.25	.162
47,44,48	46.3	3.54	.275	46,50,48	48.0	2.48	.292
45,40,35	40.0	3.52	.258	40,40,38	39.3	2.42	.190
45,47,57	49.7	3.50	.374	52,44,41	45.7	2.35	.202
37,38,37	37.3	4.00	.410	41,40,45	42.0	2.40	.212
38,30,35	34.3	4.38	.328	36,40,44	40.0	2.25	.130
40,41,33	38.0	3.88	.270	54,52,51	52.3	2.50	.125
61,62,68	63.7	3.65	.550	40,43,40	41.0	2.40	.174
Mean	42.7	3.74	.373		44.6	2.33	.173

TABLE VI
FILM E
HIGHLY ORIENTED AREAS
ORIENTATION NORMAL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation
36,22,26	28.0	2.60	.290	29,20,30	26.3	1.55	.278
32,36,24	30.7	2.05	.200	24,28,25	25.7	1.65	.326
37,26,30	31.0	2.85	.308	40,26,27	31.0	1.50	.250
43,32,34	36.3	2.35	.268	31,27,30	29.3	1.85	.112
28,28,33	29.7	2.40	.260	31,31,32	31.3	1.90	.268
34,30,27	30.3	2.60	.272	23,23,27	24.3	1.40	.112
28,28,31	29.0	3.00	.340	29,30,25	28.0	1.56	.050
26,23,23	24.0	3.26	.340	30,26,30	28.7	1.74	.326
28,28,29	28.3	3.16	.380	23,20,23	22.0	1.56	.250
25,20,20	21.7	2.80	.310	33,30,35	32.7	1.78	.142
24,30,34	29.3	2.82	.356	31,31,33	31.7	1.85	.192
25,32,28	28.3	2.86	.330	28,31,30	29.7	2.00	.580
Mean	28.9	2.73	.305		28.4	1.70	.241

TABLE VII
FILM E
SLIGHTLY ORIENTED AREAS
ORIENTATION PARALLEL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
31,32,32	31.7	3.05	.422	40,36,30	35.3	2.40	.568
43,40,34	39.0	3.06	.485	44,35,28	35.7	2.38	.680
40,37,38	38.3	3.16	.506	52,54,59	55.0	3.00	.952
38,30,31	33.0	3.32	.580	44,40,37	40.3	2.26	.408
35,31,35	33.7	3.00	.348	50,55,54	53.0	2.92	1.142
44,36,33	41.0	3.30	.448	36,37,38	37.0	2.10	.570
32,31,31	31.3	3.00	.460	41,36,36	37.7	2.55	.740
25,24,26	25.0	2.72	.382	48,34,35	39.0	2.05	.410
25,24,23	24.0	2.65	.420	40,44,41	41.7	2.20	.600
31,28,30	29.7	2.90	.340	54,55,55	54.3	2.45	.315
44,40,33	39.0	2.60	.326	54,52,50	52.0	2.65	.640
31,30,31	30.7	3.55	.482	55,52,53	53.3	2.85	.614
Mean	33.0	3.03	.433		44.5	2.48	.637

TABLE VIII
FILM E
SLIGHTLY ORIENTED AREAS
ORIENTATION NORMAL TO MACHINE DIRECTION

Samples Taken With Orientation Direction				Samples Taken Across Orientation Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
40,29,27	32.0	1.90	.248	45,40,40	41.7	2.20	.282
54,45,30	43.0	2.34	.320	57,59,51	55.7	2.86	.370
24,21,24	23.0	2.10	.275	30,27,26	27.7	1.74	.258
28,23,30	27.0	1.54	.138	45,37,34	38.7	1.68	.200
40,37,37	38.0	2.70	.528	32,30,31	31.0	2.10	.382
38,36,32	35.3	2.50	.338	36,32,33	33.7	1.80	.292
35,33,35	34.3	2.35	.425	37,31,31	33.0	2.00	.280
33,31,31	31.7	2.55	.296	28,29,31	26.0	2.15	.448
23,19,17	19.7	1.96	.292	24,19,17	20.0	1.58	.290
20,24,27	23.7	1.66	.182	37,23,28	29.3	1.85	.268
35,32,34	33.7	2.16	.310	32,38,37	35.7	1.35	.138
39,35,35	36.3	2.30	.200	36,30,35	33.7	1.70	.240
Mean	31.5	2.17	.296		33.9	1.92	.287

TABLE IX
FILM B
NONSTRETCHED FILM

Samples Taken With Machine Direction				Samples Taken Across Machine Direction			
Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.	Gauge	Average Gauge	Breaking Factor lbs./in.	Elongation in.
132,130,131	131.0	6.46	.549	122,122,130	124.7	6.02	1.950
130,126,124	126.7	6.45	2.098	125,130,135	130.0	6.10	2.228
124,123,116	121.0	8.22	2.885	135,145,150	143.3	6.10	1.620
124,124,128	125.3	6.30	2.172	131,120,121	124.0	6.00	1.298
121,117,126	121.3	6.26	1.820	123,130,130	127.7	5.96	1.318
120,127,122	123.0	6.84	3.613	117,118,128	121.0	5.95	.802
119,121,122	120.7	6.42	1.960	125,122,125	124.0	5.80	1.380
120,118,124	120.7	6.42	2.180	130,130,130	130.0	5.90	.980
127,122,125	124.7	6.45	1.622	125,132,123	126.7	5.95	2.088
118,123,119	120.0	6.30	2.000	117,119,122	119.3	5.84	1.268
122,118,116	118.7	6.16	1.534	123,125,123	122.3	5.90	1.034
123,120,121	121.3	6.25	1.988	130,132,130	130.7	5.85	2.306
Mean	122.9	6.54	2.035		127.0	5.95	1.523

Modified d.f. = 11.8 $t_{.01,\ 12} = 3.06$ t(calculated) = 3.62

TABLE X
FILM D
ANALYSIS OF VARIANCE OF BREAKING FACTORS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
Orientation	88.00	7	12.57
Error	24.14	88	.274
Total	112.14	95	

$F_{7,88,.01} = 2.87$ $LSD_{.05} = .426$

F (calculated) = 45.88

TABLE XI
FILM D
ANALYSIS OF VARIANCE OF THICKNESS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
Orientation	3,628	7	518.3
Error	6,489	88	73.7
Total	10,117	95	

$F_{7,88,.01} = 2.87$ $LSD_{.01} = 9.21$

F (calculated) = 7.03

TABLE XIII
FILM E
ANALYSIS OF VARIANCE OF BREAKING FACTORS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
Orientation	35.73	7	5.10
Error	7.81	88	.089
Total	43.54	95	

$F_{7,88,.01} = 2.87$ $LSD_{.05} = .242$

F (calculated) = 57.4

TABLE XIII
FILM E
ANALYSIS OF VARIANCE OF THICKNESS

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square
Orientation	3,989.93	7	569.99
Error	3,701.09	88	42.06
Total	7,691.02	95	

$F_{7,88,.01} = 2.87$ $LSD_{.05} = 5.26$

F (calculated) = 13.55

TABLE XIV
FILM D
BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCE OF BREAKING FACTORS

Observation[a]	Sum of Squares	Variance	Logarithm of Variance
(1)	247.88	22.53	1.35276
(2)	77.42	7.04	0.84757
(3)	222.51	20.23	1.30600
(4)	80.80	7.35	0.86624
(5)	76.67	6.97	0.84323
(6)	51.79	4.71	0.67302
(7)	49.02	4.46	0.64933
(8)	41.82	3.80	0.57978
Total		77.09	7.11789

Mean Variance = 9.64 $\quad \chi^2_{.01,7} = 18.48$

Log Mean Variance = 0.98408 $\quad \chi^2$ (calculated) = .846

[a] Observation codes correspond to those of Table I, page 23.

TABLE XV
FILM D
BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCE OF THICKNESS

Observation	Sum of Squares	Variance	Logarithm of Variance
(1)	29291.0	2671.9	3.42681
(2)	32211.4	2928.3	3.46669
(3)	31059.9	2828.6	3.45157
(4)	34370.7	3124.6	3.49479
(5)	18970.2	1724.6	3.23669
(6)	18159.7	1650.9	3.21770
(7)	15899.1	1445.4	3.15999
(8)	21739.3	1976.3	3.29595
Total		18360.6	26.75009

Mean Variance = 2295.06 $\quad X^2_{.01,7} = 18.48$

Log Mean Variance = 3.36080 $\quad X^2$ (calculated) = 3.32

TABLE XVI
FILM E
BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCE OF BREAKING FACTORS

Observation	Sum of Squares	Variance	Logarithm of Variance
(1)	168.40	15.31	1.18498
(2)	65.12	5.92	0.77232
(3)	90.71	8.25	0.91645
(4)	34.89	3.17	0.50106
(5)	110.76	10.07	1.00303
(6)	75.16	6.83	0.83442
(7)	57.99	5.27	0.72181
(8)	45.77	4.16	0.61909
Total		58.98	6.55316

Mean Variance = 7.37

Log Mean Variance = 0.86747

$X^2_{.01,7} = 18.48$

X^2 (calculated) = .943

TABLE XVII
FILM E
BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCE OF THICKNESS

Observation	Sum of Squares	Variance	Logarithm of Variance
(1)	22604.6	2055.0	3.31281
(2)	24023.1	2183.9	3.33921
(3)	9789.8	890.0	2.94938
(4)	10153.5	923.1	2.96523
(5)	13424.7	1220.4	3.08650
(6)	24522.2	2229.3	3.34817
(7)	12405.6	1127.8	3.05213
(8)	14636.7	1330.6	3.12405
Total		11960.0	25.17748

Mean Variance = 1495.0

Log Mean Variance = 3.17464

$X^2_{.01,7}$ = 18.48

X^2 (calculated) = 5.35

TABLE XVIII
FILM E
HIGHLY ORIENTED AREAS
ORIENTATION PARALLEL TO MACHINE DIRECTION

Samples Taken With Machine Direction			Samples Taken Across Machine Direction		
Gauge	Average Gauge	Breaking Factor lbs./in.	Gauge	Average Gauge	Breaking Factor lbs./in.
73,69,59	67.0	5.64	54,50,52	52.0	2.98
73,68,64	68.3	7.21	73,72,70	71.7	4.11
56,57,53	55.3	5.20	70,67,63	66.7	3.55
56,55,58	56.3	6.79	60,59,60	59.7	2.78
61,59,56	58.7	5.56	52,54,63	56.3	3.00
55,56,52	54.3	4.58	70,66,64	66.7	3.32
71,63,70	68.0	6.22	53,55,51	53.0	3.14
63,65,65	64.3	6.75	62,59,60	60.3	3.05
60,55,55	56.7	7.93	77,82,82	80.3	3.44
62,62,63	62.3	6.76	55,55,56	55.3	3.20
Mean	61.1	6.26		62.2	3.26

TABLE XIX
FILM B
NONSTRETCHED FILM

Samples Taken With Machine Direction				Samples Taken Across Machine Direction			
Gauge	Average Gauge	Strength at Yield lbs.	Strength at Break lbs.	Gauge	Average Gauge	Strength at Yield lbs.	Strength at Break lbs.
122,128,125	125.0	6.44	4.74	135,133,135	134.3	5.70	4.00
125,130,131	128.7	6.10	4.45	131,129,132	130.7	5.75	4.18
125,132,134	130.3	6.00	4.60	132,136,137	135.0	5.85	4.18
126,126,130	127.3	6.05	4.40	130,130,124	128.0	5.55	3.92
135,132,140	135.7	6.05	4.80	128,127,126	127.0	5.60	4.18
128,132,133	131.0	5.38	4.82	125,126,130	127.0	5.55	4.00
130,128,130	129.3	6.10	4.52	130,130,132	130.7	5.60	4.10
126,123,126	125.0	6.00	4.52	121,125,126	124.0	5.50	3.98
126,124,125	125.0	5.85	4.40	131,130,130	130.3	5.50	3.90
130,132,134	132.0	5.90	4.50	128,126,132	128.7	5.50	4.08
Mean	128.9	5.99	4.58		129.6	5.61	4.05

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