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A Synthetic Material for Detecting Hazardous Edges

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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Abstract

An investigation of poly(tetrafluorethylene) pressure-sensitive tape (PTFE tape) was conducted to determine its suitability as an indicator of the hazard potential of exposed edges on consumer products when used with the sharp edge testing device. In addition, criteria were established by which suitable tape could be specified as a standard material for detection of sharp edges.

From a study of many PTFE tapes having different physical and mechanical properties, it was concluded that in order to specify the tape as a suitable material to be used with a sharp edge testing device, the tape should be tested against two standard edge geometries. One of the standard edges will cause the tape to be totally penetrated, representing a bleeding cut or a breakthrough of the epidermis of human skin when an unsafe edge is contacted. The other edge will not totally penetrate the tape, representing a no-bleed cut when a safe edge is contacted by a consumer.

Recommendations are presented to specify the proper PTFE tape based on the tape's thickness and ability to pass a performance test against two standard edge geometries under given force loading conditions. These edge geometries are solely for the purpose of specifying the tape and are not intended to be interpreted as guidelines for actual edges placed on consumer products.

Introduction

The Consumer Product Safety Commission has been concerned with the dangers of sharp edges on consumer products. There exists no theoretical or analytical solution to describe the cutting mechanism of materials. The only accurate way to determine whether a sharp edge will cut human skin is to test in vivo skin against the edge. This, of course, is impractical in terms of personal safety. Therefore, the approach in these studies was to test in vitro excised skin against different edge geometries to see how they cut at different force levels. Once this was determined a further attempt was made to determine a relationship between an edge which cut skin at a given force level and this same edge cutting a synthetic material. Thus, a synthetic material can be substituted for tissue in testing sharp edges and their ability to cut human skin following a given safety criterion.

This report is a continuation of the study originated by Sorrells and Berger 1/ to establish a procedure for detecting hazardous edges. Due to the complex nature of the problem of obtaining a suitable synthetic material which would detect dangerous exposed edges on consumer products, an empirical approach was used in this study. This approach consists of utilizing a device which could detect hazardous edges when used with a suitable synthetic material.

Sorrells designed a sharp edge tester (see Figure 1), as described in the previous report, which would differentiate between unsafe edges and safe edges under a mode previously termed "casual handling." In the "casual handling" mode there is a normal force between the skin and the edge, a relative velocity parallel to the edge, but no relative velocity in the normal direction (except when cutting occurs).

In the previous study, forty different materials were evaluated for their ability to discriminate edges in a manner similar to that of human skin. As a result of this study poly(tetrafluoroethylene)* was selected as a test material for use with the sharp edge tester because (1) it discriminates between edges in the same way that human skin does, (2) it is free of liquid plasticizers that may evaporate or migrate and cause changes in the properties of the tape, (3) the polymer is highly stable, and (4) it is relatively convenient to mount on the tester because of the adhesive backing.

The method of choosing sharp edge safety criteria in this study was to select an injury level and a force developed between the edge and human skin, that would create this type of injury. In Sorrells' study 2/ edges with many different geometries were used to cut human skin. From these experiments two different safety criteria were chosen by the Consumer Product Safety Commission, depending on the accessibility of an edge. An exposed** edge would be considered safe if it did not break

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*Hereafter abbreviated PTFE.

**Whether an edge is easily accessible (exposed) or not is completely arbitrary. The manner in which the user of a product contacts an edge will depend on the particular product, the way it is used, and for whose use it is intended.

through the epidermis of the human skin when the normal force between the edge and the skin was 89 newtons (20 pounds). No breakthrough of the epidermis corresponds to a "no bleed" level cut. The second criterion required that, with a force of 17.8 newtons (4 pounds), the edge would not penetrate the human skin greater than 80 percent of the total thickness of skin for an edge not easily accessible when a product is in normal use. Thus, these safety criteria can be expressed as:

Safety Criterion (A) - 89 newton force, no epidermal breakthrough

Safety Criterion (B) - 17.8 newton force, less than 80 percent penetration of the total skin thickness

Two pairs of edges were selected from a group of test edges, against which the synthetic material was tested for each safety criterion. Figure 2 gives a description of all edges used in these experiments. One edge in each pair was not to penetrate the material completely while the other was to cut through the material. Thus, for the safety criteria:

Safety Criterion (A) - discriminate edge L unsafe and edge M as safe

Safety Criterion (B) - discriminate edge A unsafe and edge B as safe

A description of the experimental testing performed in order to obtain a method to specify properly a suitable synthetic cut indicator for use with a sharp edge testing device is presented in this report. In addition, this report describes a performance test for the tape and the proper thicknesses of tape material to specify which tapes are to be used with the sharp edge tester.

Tape Testing Experiments

Experiments were performed to find a PTFE tape that would satisfy the dual safety criteria as mentioned in the introduction. Additional tests were made in an attempt to relate the mechanical properties of the tapes to their ability to meet the safety criteria. It was hoped that it would be possible to specify the correct PTFE tape to be used on a sharp edge tester by stating the required mechanical and physical properties. The PTFE tapes were tested for the following properties:

1. The maximum breaking strength

2. The maximum tensile strength

3. Ultimate elongation

4. Film thickness and adhesive thickness

5. Whether the tape would discriminate safety criteria (A) and (B)

The first three properties listed above were tested using a universal testing machine according to ASTM Standard D-882. Tape samples were pulled apart at a rate of 50 cm/min, with an initial grip separation of 5 cm, until they broke. The results were recorded on a strip chart and calculations were made based on the maximum load applied to the tape.

The film thickness and adhesive thickness of each tape were measured using a dead weight dial micrometer, having a 112 gram (4 oz) weight, according to ASTM Standard D-374. The load was applied normal to the tape surface which contained the adhesive coating. The adhesive coating was then removed with solvents and the film thickness measured. The adhesive thickness was determined from the difference in the total thickness and the film thickness.

The safety criterion(A) and (B) tests were performed with a 16.9 newton force for criterion (A) and a 4.45 newton force for criterion (B) between the edge and the tape using the sharp edge testing device. It was established in earlier work 3/ that a 16.9 newton force applied to an edge and tape will discriminate sharp and dull edges in the same way as human skin does at a 89 newton force level between an edge and skin. In addition, a 4.45 newton force applied to an edge and tape will discriminate sharp and dull edges similarly to human skin at 17.8 newtons. The tape was placed on the sharp edge testing device's mandrel and allowed to rotate against the test edges with the appropriate force applied to the edge during one revolution. For safety criterion (A), edge L was to penetrate the tape completely and edge M was not to penetrate the tape completely. Safety criterion (B) required that edge A penetrate the tape and edge B not penetrate the tape completely. The results are shown in Table 1. The manufacturing processes of most of the tapes are listed in order to see whether they correlate with the tape properties. The breaking strength, tensile strength and elongation properties of the tapes show little or no correlation to the tape's ability to satisfy the discriminations (A) and (B). The percent standard deviation of the measurements typically varied from 5 to 15 percent.

There appears to be a strong relation between a tape's ability to discriminate the safety criteria and its thickness. It is evident (see results for tapes 5, 6, 8 and 9) from the data that the tape should have a film thickness of 0.075 to 0.10 mm (3 to 4 mils). These measurements of thickness had a 2 percent standard deviation. This indicates that most of the tapes were of uniform thickness. An examination of the manufacturing processes of the tapes did not show a correlation to the tape's properties.

An examination of the criteria data of Table 1 shows that 6 tapes were able conservatively to satisfy criterion (A) more than 80 percent of the time. Conservative here means that in terms of consumer safety, the tape will determine a safe edge hazardous when the edge does not pass the safety criteria. Only two tapes were able to discriminate criterion (B) conservatively. These two tapes were able to discriminate both criteria (A) and (B) conservatively.

The problems encountered in trying to obtain a tape that would meet both safety criteria were many. No relationship could be established between the mechanical properties of the tapes and their ability to meet the safety criteria. Nevertheless, the thickness of the tapes can be correlated to the tape's ability to meet the safety criteria; that is, suitable thickness should be in the range 0.075 to 0.10 mm (3 to 4 mils). However, thickness alone would not be enough to specify the tape. The major problem appears to be related to the chosen safety criteria and the selected edges to meet the safety criteria.

In reviewing the original skin cutting data several factors were observed which help explain the problems of obtaining a single tape material to meet both criteria. Figure 3 is a plot of the percent depth of cut* as a function of designated edge geometries, while maintaining a 4 pound (17.8 newtons) force between the edge and the skin sample. Figure 3 shows the human skin-cut data developed by test edges A and B at 17.8 newtons (4 pounds). Due to the similarities of edge geometries and manner of cutting human skin there exists little difference in the cutting potential of these edges. Results shown in figure 4 show also that with this test there is difficulty in differentiating between cutting potentials of edges L and M. It was concluded that it is impractical to find a tape which could make such precise distinctions as required by these selected edge pairs.

After discussion with the Consumer Product Safety Commission project manager, it was decided to eliminate safety criterion (B). It was also decided that two new edges be selected for safety criterion (A) which would have a larger difference in their cutting potential. Edge K (90° X 0.05 mm) was selected as a representative edge for indicating a break in the epidermis of human skin and as an unsafe edge. Two new edges N (90° X 0.25 mm) and O (90° X 0.30 mm) were added as safe edges. These additional edges were selected because there would be less difficulty encountered in fabricating them as standard edges. A selection of one of the two new edges as a safe edge could be made after retesting the tapes against each of them and also edge K. The final two edges selected could then be used to specify the mechanical properties or the cuttability of the tape under a single force loading condition of 16.9 newtons using the sharp edge tester. Thus, the tape could be specified by testing it against two standard edge geometries under a single force loading, and the tape's thickness. A single safety criterion was established from these decisions against which all edges on consumer products could be tested:

Safety Criterion - 89 newton force, no epidermal breakthrough

The percent depth of cut, D, is the ratio of the thickness of tissue at the bottom of a cut to that of the total thickness of skin adjacent to the cut expressed as a percentage. This is plotted as the ordinate value in figures 3 and 4.

Further testing was conducted on the tapes using the new edges selected. This consisted of retesting the tapes for their ability to meet the single safety criterion against edges K, N and O using the sharp edge tester. The results are presented in Table 2. Edge K will cut all the tapes tested, except tape 5 which has a thickness in excess of 0.125 mm (5 mils), indicating edge K as an unsafe edge. Edge N did not cut through 9 of the 11 tapes tested. Edge O showed 10 of the 11 tapes tested as able to discriminate this edge as safe. From these results edge K and edge N were selected as the two standard edge geometries against which to test the tape's performance to detect hazardous edges. Edge N, instead of edge O, was selected because it was more similar to the geometry of edge M, which was used in the human skin cutting experiments. Thus the safety criterion can be stated in terms of these edges as:

Safety Criterion - discriminate edge K unsafe and edge N as safe

Performance Test of Synthetic Cut Indicator

The cut indicator to be used with the sharp edge tester should be poly(tetrafluorethylene) pressure-sensitive tape with a film thickness of 0.075 to 0.10 mm (3 to 4 mils) and with an adhesive backing of 0.0375 to 0.075 mm (1.5 to 3 mils). The tape must also pass a performance test against two standard edge geometries: that is, the tape must be cut (totally penetrated by the edge in at least one point on the tape specimen) with a 90° X 0.05 mm (2 mils) edge and not be cut with a 90° X 0.25 mm (10 mils) edge when the tape is allowed to rotate against each edge with a force of 16.9 newtons applied using the sharp edge tester.

The standard edges should be constructed with a tolerance of $\pm$ 3° for the included angle of the edge and with a tolerance of $\pm$ 0.0125 mm (0.5 mil) for the radius. The edges used at NBS for making the safety discriminations were fabricated of tool steel, oil hardened to a Rockwell hardness of 60 - 62. The radius of the edges were finished to have an average surface roughness no greater than 8 microinches.

Summary

The PTFE sensitive tape described in the previous section can be used as a hazardous edge detector when used with the sharp edge tester. The PTFE tape must meet the proper thickness specifications and pass the performance test against two standard edge geometries using the sharp edge tester. An edge may be considered hazardous if the tape is completely penetrated at a contact force of 16.9 newtons (3.8 pounds), the equivalent of a breakthrough of human skin when the contact force is 89 newtons (20 pounds) between skin and the edge. This procedure then may establish a safety criterion by which edges on consumer products may be tested.

The two selected edge geometries to test the tapes are intended solely for the purpose of indicating whether or not the PTFE tape is suitable for use as a cut indicator when used on the sharp edge testing device. In no way should these edge geometries be interpreted as guidelines for edges placed on consumer products. The edges presented in Figure 2 show many different edge geometries that will cut human skin at the 16.9 newton (20 pound) force level. Edges on consumer products will have to be tested individually against the PTFE tape to insure that they are not hazardous to the consumer.

Table 1. Physical Description of Tapes Evaluated as A Synthetic Cut Indicator

Sample #	No. of Test Specimens	Film Thickness mils	Thickness Total mils	Thickness Adhesive mils	Criterion (A) Percent Passed 3.8 lbf	Criterion (B) Percent Passed 1 lbf	Breaking Strength lb/in (width)	Tensile (psi)	Elongation %	Manufacturing Method
1	20	3.54	4.65	1.11	0	0	18.3	5240	353	Skived with silicone adhesive
2	10	3.25	4.85	1.60	100	90	18.8	5780	391	Skived with silicone adhesive
3	10	3.29	6.48	3.19	80	70	18.0	5490	318	Skived with acrylic adhesive
4	10	3.56	5.51	1.95	100	80	28.4	7990	455	Extruded sintered with silicone adhesive
5	10	5.47	7.91	2.44	0	0	39.4	7200	651	Extruded with acrylic adhesive
6	10	5.74	7.82	2.08	0	0	28.1	4910	238	
7	15	3.3	5.46	2.16	87	100	17.3	5240	586	Cast with acrylic adhesive
8	15	4.3	6.17	1.87	67	0	22.7	5280	708	Cast with acrylic adhesive
9	8	4.76	6.76	2.00	0	0	41.4	8670	186	Extruded

Table 1. Continued

Sample #	No. of Test Specimens	Film Thickness mils	Thickness Total mils	Thickness Adhesive mils	Criterion (A) Percent Passed 3.8 lbf	Criterion (B) Percent Passed 1 lbf	Breaking Strength lb/in (width)	Tensile (psi)	Elongation %	Manufacturing Method
10	15	3.3	5.93	2.63	<u>80</u>	67	25.8	7250	396	Skived with silicone adhesive
11	15	3.33	4.82	1.49	<u>60</u>	40	17.9	5390	453	
12	15	3.19	5.96	2.77	93	46	30.2	9480	464	Skived
13	15	3.26	6.02	2.76	<u>80</u>	73	24.3	7410	390	Skived with silicone adhesive

Note: **If the value is underlined for criterion (A) or (B), the edge failed to pass the discrimination test conservatively. That is, the tape would determine an edge too sharp that should pass the discrimination test.**

The equipment used to make the measurements was calibrated in customary units; and accordingly, the data has been given in customary units rather than metric (SI). Final results and conclusions drawn are given in SI or both customary and SI.

Table 2. Discrimination Test Results

Sample #	No. of Tests	Edge K 90° X 2 mils	Edge N 90° X 10 mils	Edge O 90° X 12 mils
		The percent of successful discriminations are shown for each edge		
1	20	100%	45%	58%
2	10	100%	100%	100%
3	8	100%	100%	100%
4	10	100%	100%	100%
5	8	0	100%	100%
7	10	100%	100%	100%
8	10	100%	100%	100%
10	10	100%	100%	100%
11	10	100%	100%	100%
12	10	100%	100%	100%
14	10	100%	90%	100%

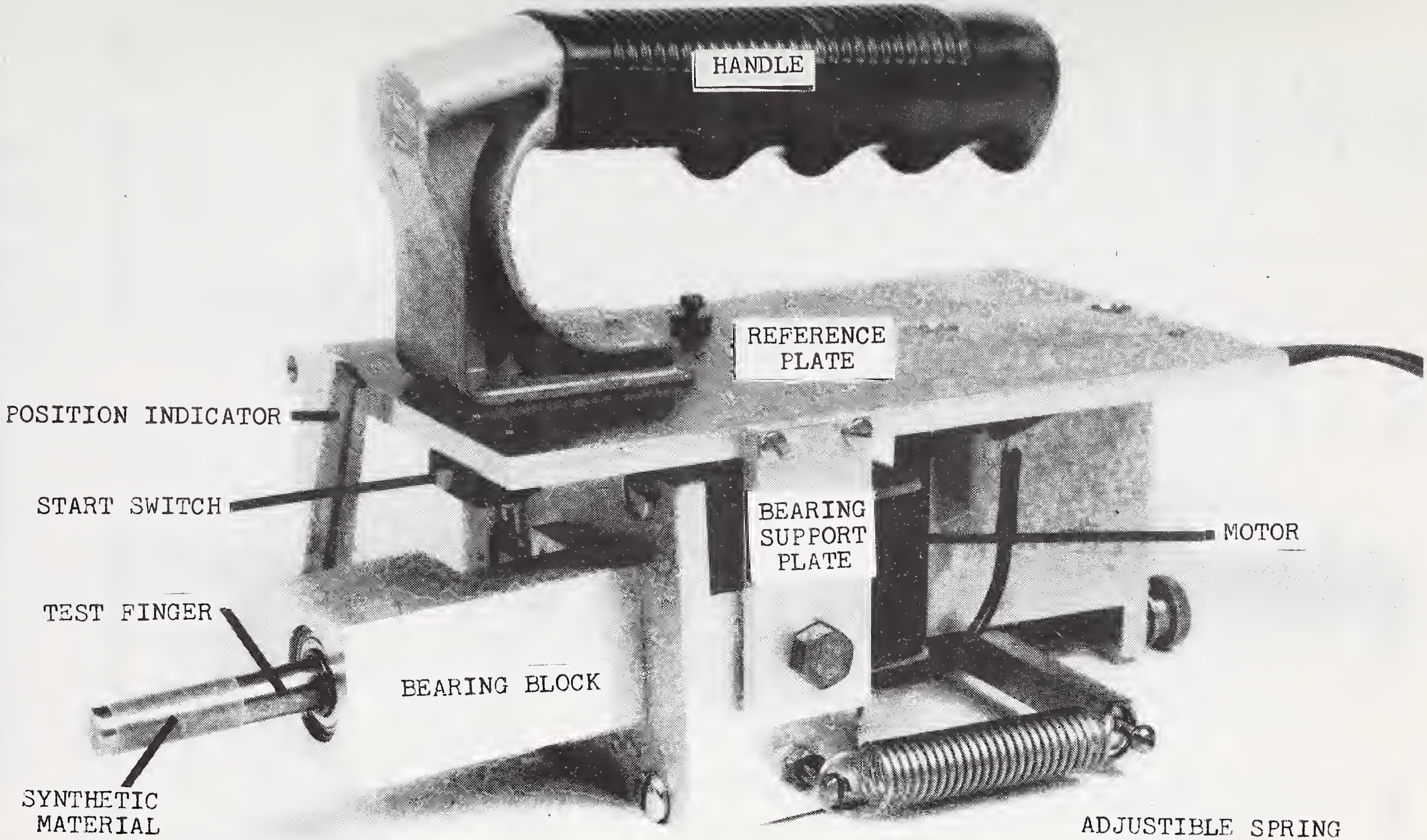
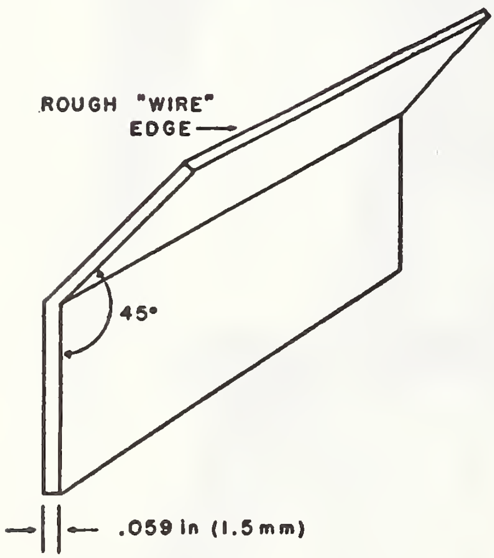
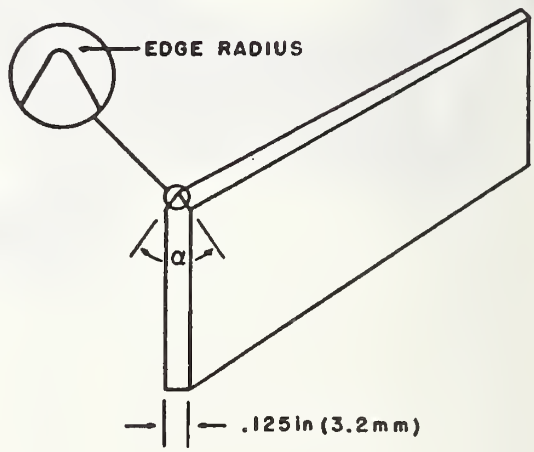


FIGURE 1. PHOTOGRAPH OF SHARP EDGE TESTER

EDGE	ANGLE (α) degrees, radians	RADIUS	TYPE
A	60°, π/3	.000 in	GROUND
B	90°, π/2	.000	GROUND
C	—	—	SHEARED
D	—	—	SHEARED
E	105°, 7π/12	.000	GROUND
F	90°	.000	GROUND
G	15°, π/12	.002 (.05 mm)	GROUND
H	30°, π/6	.002	GROUND
I	60°	.002	GROUND
J	15°	.004 (.10mm)	GROUND
K	90°	.002	GROUND
L	90°	.004	GROUND
M	90°	.008 (.20mm)	GROUND
N	90°	.010 (.25mm)	GROUND
O	90°	.012 (.30mm)	GROUND



TYPICAL SHEARED EDGE



TYPICAL GROUND EDGE

FIGURE 2. DESCRIPTION OF TEST EDGES

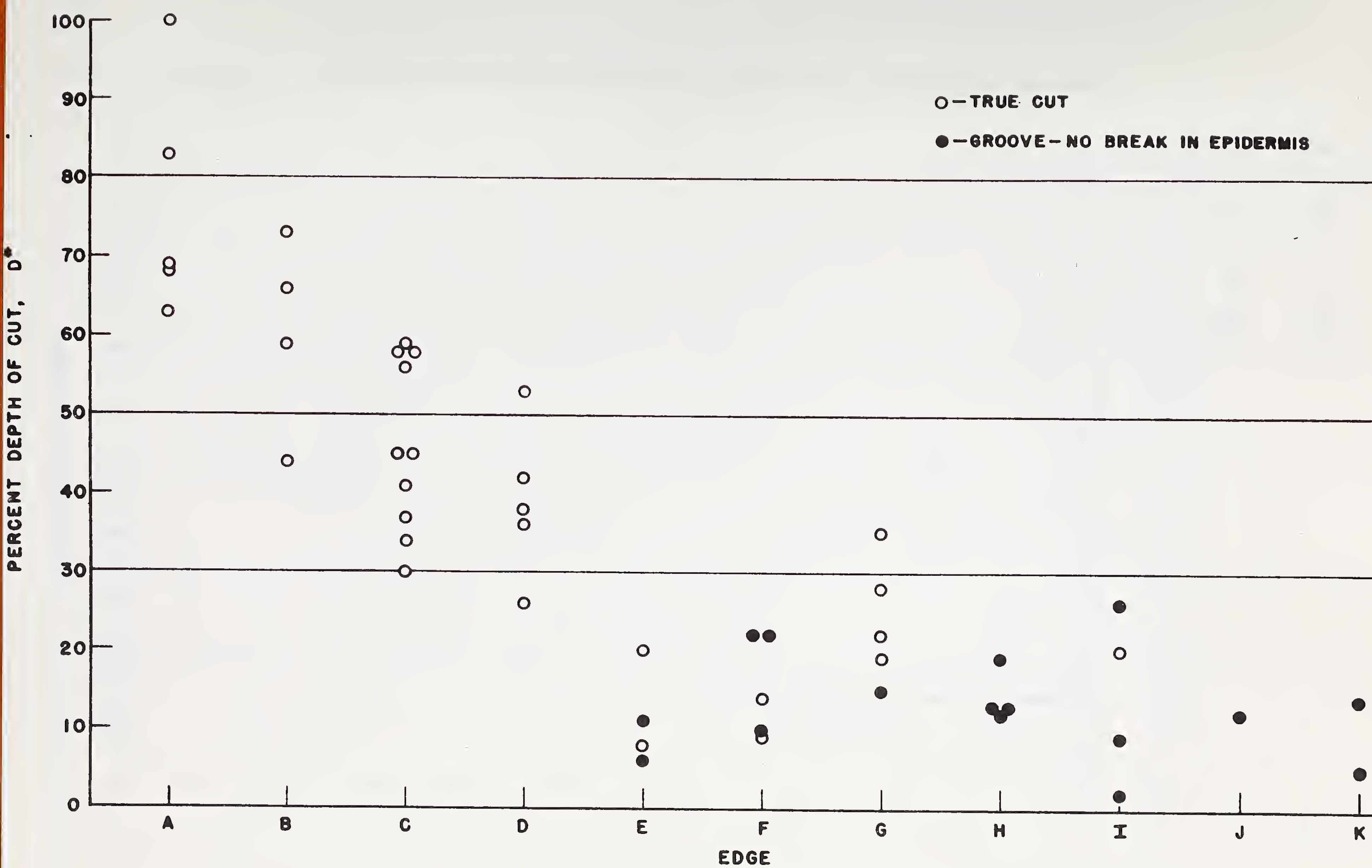


FIGURE 3. HUMAN SKIN CUT DATA FOR ALL TEST EDGES AT 4 POUNDS (17.8 NEWTONS)

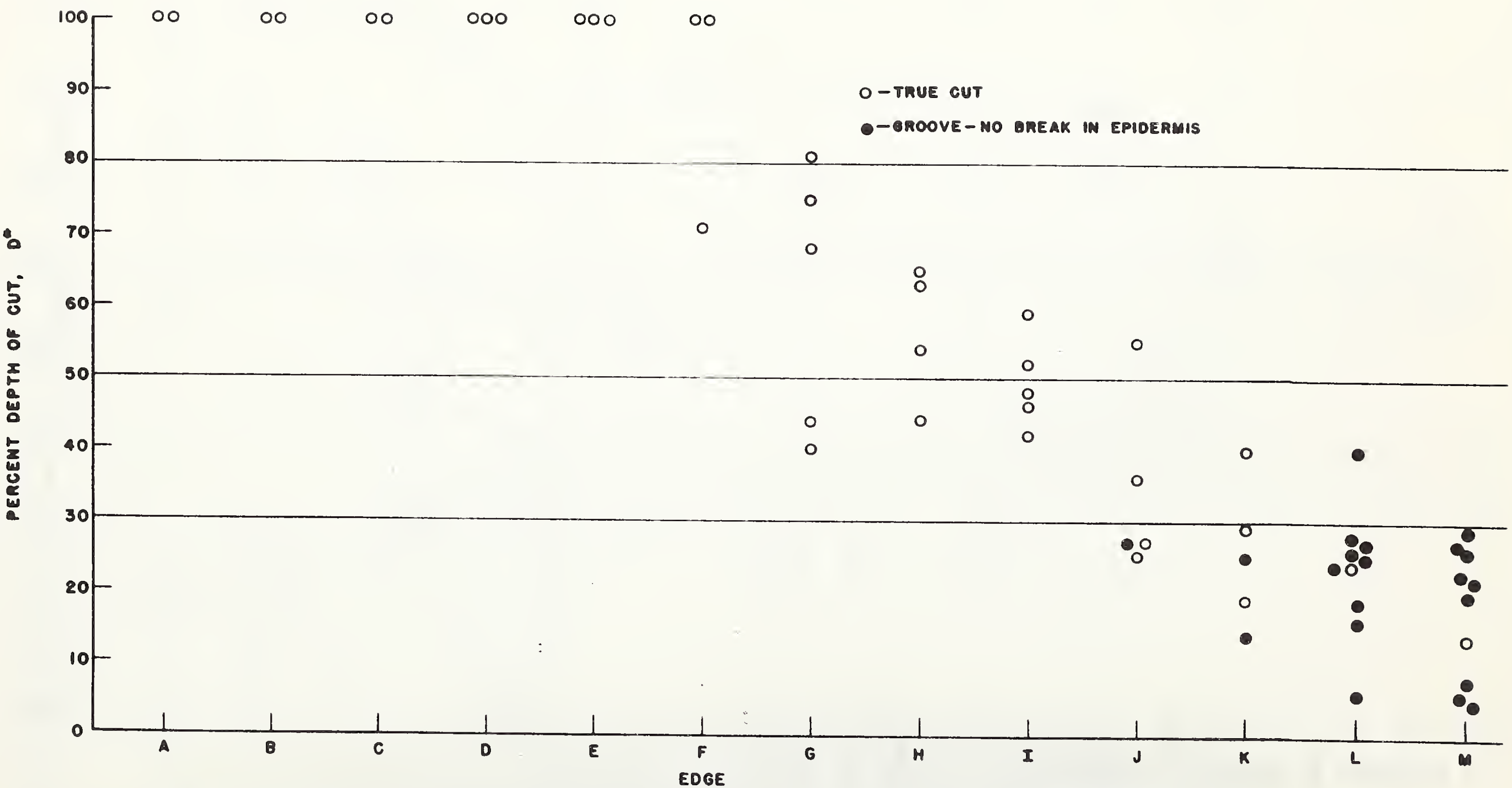


FIGURE 4. HUMAN SKIN CUT DATA FOR ALL TEST EDGES AT 20 POUNDS (89.0 NEWTONS)

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3. Op cit

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

An investigation of poly(tetrafluorethylene) pressure-sensitive tape (PTFE tape) was conducted to determine its suitability as an indicator of the hazard potential of exposed edges on consumer products when used with the sharp edge testing device. In addition, criteria were established by which suitable tape could be specified as a standard material for detection of sharp edges.

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17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Consumer; discrimination; edges; geometry; hazardous; injury; safety criterion; sharp edge tester; skin; synthetic cut indicator; tape

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