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COMPARISON OF THE PROPERTIES OF PARACHUTE WEBBINGS WOVEN ON SHUTTLE AND SHUTTLELESS LOOMS

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This study compares the properties of shuttle and shuttleless webbings for three fiber types: nylon 6,6, nylon 6, and polyester. Tensile strength, elongation and energy absorption were measured on the original webbings and after hex bar abrasion, weathering, high speed impact, and edge abrasion.

For all webbing types there were no statistically significant differences in tensile properties between webbings produced on shuttle or shuttleless looms. Among the fiber types, the polyester webbings showed several significant differences. However, the polyester constructions were not optimized for performance, and many of the differences observed could have been significantly affected by the construction.

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SUMMARY

This study compares the properties of webbings produced on shuttle and shuttleless looms. The narrow fabric industry is currently undergoing a change to shuttleless looms. This raises concerns for webbing supply and cost under the existing specification which requires that critical (life support) applications use only nylon 6,6 webbings produced on a shuttle loom. This study compares the properties of six webbing types (Types VI, VIII, X, XIII, XIV, and XXII), in shuttle and shuttleless constructions, both uncoated and resin coated, for three fiber types: nylon 6,6, nylon 6, and polyester. Various physical properties were examined. Tensile strength, elongation and energy absorption were measured on the original webbings and then after various test conditions: hex bar abrasion, weathering, high speed impact, and edge abrasion. High speed impact and edge abrasion were tested by methods devised for this project.

For all webbing types, there were no statistically significant differences in tensile properties between webbings produced on shuttle or shuttleless looms. In particular, resistance to high speed impact and edge abrasion were equivalent for both weaving methods. In addition, no differences in the amount of edge abrasion occurring on the catch-cord and non-catch-cord edge of the shuttleless webbings were observed.

Among the fiber types, the polyester webbings showed several significant differences. However, these constructions were formed by straight substitution of 1000 denier polyester for 840 denier nylon, and not truly optimized for performance. Many of the differences observed could not be attributed directly to an inherent property of the polyester fiber, but could have been significantly affected by the construction. The most notable differences were: original elongation of most polyester webbings were about 75 to 85% of the equivalent nylon 6,6 shuttle webbings. This gave energy values in the range of 65 to 85% of the nylon 6,6 shuttle webbings Several individual coated polyester constructions showed comparatively low tensile strength values after accelerated weathering (<85%). Polyester webbings showed slightly increased napping tendency during hex bar abrasion, and in the uncoated state showed relatively large strength reductions compared to nylon 6,6 and nylon 6. After impact cycling, polyester webbings show considerable loss of tensile elongation and energy absorption. However, in all of these cases, it must be emphasized that constructional effects could explain some or all of the differences.

PREFACE

This report was prepared by Albany International Research Co. under U. S. Government Contract No. DAAK60-85-C-0064. The study was conducted between May 1985 and February 1987. Ms. Jeanine Duhamel of the Natick Center Procurement Office was the Contracting Officer. The Contracting Officer's Representative was Mr. James E. Mello, Project Officer.

The authors wish to express their thanks to several Albany International Research Co. co-workers who assisted in the study. Ms. Ruth Hall performed the majority of the laboratory work with the assistance of Ms. Janet Finn and Ms. Elizabeth Page. Mr. Joseph Panto provided assistance in running the Weatherometer exposures. Mr. Robert Sebring designed and assembled the impact testing modifications. Also, Mr. James Tierney of the Aero-Mechanical Engineering Directorate at the Natick RD&E Center provided assistance during the impact testing at Natick.

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COMPARISON OF THE PROPERTIES OF PARACHUTE WEBBINGS WOVEN ON SHUTTLE AND SHUTTLELESS LOOMS

I. INTRODUCTION

The narrow fabric industry is undergoing a change from shuttle to shuttleless looms. The specification now existing for nylon 6,6 webbings in critical (life support) applications requires the webbing to be constructed on a shuttle type loom. Because of the decreasing availability of webbings produced on shuttle looms, this raises concerns for both webbing supply and increased cost. These problems have been recognized over the last 10 to 15 years, and several steps have been taken to address them. On May 10, 1974, Revision H of MIL-W-4088 allowed the use of shuttleless loom produced webbings for non-critical use (Class 2), the same revision also allowed the substitution on nylon 6 for nylon 6,6 for certain webbings [1].

In 1977 and 1978 a study was conducted by Gardella and Devarakonda [2] at NRDEC (then NARADCOM) comparing the properties of selected webbings woven on both shuttle and shuttleless looms. From this study, they concluded that both types performed equally well in all noncritical applications, but suggested further testing should be conducted for critical life support applications. They also concluded at that time that cost savings of approximately 5% could be expected from using shuttleless webbings.

The study which follows extends this work to several additional webbing types, and further considers the use of nylon 6 and polyester in webbing applications. One of the particular concerns is the effect of the non-interlaced edge on a shuttleless webbing which results from a double pick inserted from one side only during weaving. This edge in a shuttleless construction is typically bound together by knitting in a catch-cord yarn. The behavior of this structure when subjected to edge abrasion during use in related hardware, and during conditions of impact loading, is the point of concern. For example, would the catch-cord edge show unusual edge abrasion properties, or would it "unzip" with impact? To determine if the shuttleless webbings would maintain the same tensile properties after edge abrasion and high speed impact, two test methods were developed for this project.

The study which follows compares the tensile properties of six webbing types, in shuttle and shuttleless constructions, both uncoated and resin coated, for three fiber types: nylon 6,6, nylon 6, and polyester. A number of physical properties such as thickness, weight, and lateral curvature are examined. Tensile strength, elongation and energy absorption are measured on the original webbings and then after various test conditions or "treatments": hex bar abrasion, weathering, high speed impact, and edge abrasion.

II. MATERIALS

Webbings made from nylon 6,6, nylon 6 and high strength polyester yarn, all dyed olive drab shade 7 (OD-7) were obtained by subcontract to Narricot Industries, Inc. (Cheltenham, PA). Six webbing types were fabricated: Types VI, VIII, X, XIII, XIX, and XXII according to the specification requirements of MIL-W-4088J, Table 2. Selected specification requirements are shown in Table 1 of this report. Each webbing was fabricated in both a shuttle and shuttleless version, and in the uncoated and resin coated states. In the following report, all shuttle webbings are denoted Class 1 and all shuttleless webbings Class 2, for all fiber types. Within the specification, however, only nylon 6,6 shuttle loom webbings may be Class 1; nylon 6, regardless of the loom used, is Class 2; and polyester is not approved for the current spec. In the interests of clarity, however, Class 1 (shuttle) and Class 2 (shuttleless) have been adopted for this report. A total of 72 webbings were produced. Additionally, 100 linear yards of each of the 36 resin-coated webbings were produced to be delivered to the Government at completion of the project.

As the specific gravity of polyester is greater than that of nylon, an adjustment in the polyester yarn denier was made so that the polyester webbings would be expected to conform to thickness and width requirements. This was done by using 1000-denier polyester (Allied polyester Type IW70) in place of 840-denier nylon, with the aim of substituting directly, ply for ply, and end for end. In several of the constructions, difficulties were encountered with this approach, as the specified number of picks per inch could not be inserted. Accordingly, the picks per inch and/or filling ply and denier were adjusted to come as close as possible to the thickness requirements of MIL-W-4088. As development of optimized polyester constructions was not an objective of this work, we accepted these webbings as received for the required comparative testing. Details of the constructions may be found in the results and discussion section.

TABLE 1. Physical and Mechanical Requirements - MIL-W-4088J

Characteristic	Requirements						FED-STD-191A Test Method
Type	VI	VIII	X	XIII	XIX	XXII	
Width (inch)	1-23/32 ± 1/16	1-23/32 ± 1/16	1-23/32 ± 3/32	1-23/32 ± 3/32	1-3/4 ± 3/32	1-23/32 ± 3/32	Visual
Thickness (inch)	0.03-0.05	0.04-0.07	0.10-0.14	0.08-0.12	0.10-0.13	0.09-0.12	5030
Weight (oz/lin yd)[a] (max)	1.15	1.60	3.70	2.90	4.10	3.50	5041
Breaking Strength (lb) (min)	2500	4000	9500	7000	10,000	9500	4108
Ends Per Inch (min) (face and back)	114	166	257	281	280	259	5050
Binder	----	----	31	34	----	----	5050
Picks Per Inch (min)[b]	21	18	22	24	18	18	5050
Yarn Ply (min)							
warp	2	2	3	2	3	3	Visual
filling	2	2	2	2	2	2	Visual
binder	----	----	1	1	----	----	Visual
Yarn Size and Filament before Dyeing[c]							
warp	840/140	840/140	840/140	840/140	640/140	840/140	d
filling	840/140	840/140	840/140	840/140	840/140	840/140	d
binder	---	---	840/140	840/140	---	---	d

[a]Does not apply to polyester webbings.
[b]When woven on shuttleless looms, two filling yarns are inserted in each shed; thus, the filling yarn size will be one-half that used for shuttle loom webbing.
[c]Yarn size and filament count shall be adjusted as required to yield webbings conforming to the width and thickness requirements specified herein. It is anticipated that the differences in specific gravity and thickness between nylon and polyester would be compensated by the use of 1000-denier polyester in place of 840-denier nylon.
[d]Contractor's Certificate of Compliance.

III. TEST METHODS

1. Thickness

Determined according to FED-STD-191A, Test Method 5030 [3].

2. Weight

Determined according to FED-STD-191A, Test Method 5041 [4].

3. Lateral Curvature

Determined according to MIL-W-4088J, para. 4.5.1 [1].

4. Construction

Determined according to FED-STD-191A, Test Method 5050 [5].

5. Tensile Testing

A method similar to FED-STD-191A, Test Method 4108 was used [6]. The jaws, gripping procedures, and test speeds were as described in this method. Our original intention was to use an extensometer to measure elongation, rather than gauge marks, as called for in Method 4108. An extensometer would provide a direct trace of load vs. elongation which could be analyzed by computer to give rapid and accurate measurements of energy and elongation at break. Several problems were encountered with this testing procedure. The extensometers currently available are not rugged enough for use with these webbings. During the break and subsequent recoil of the webbing, the extensometer is slammed against the capstan jaws. For low strength webbings, this results in the constant need to tighten the extensometer assembly, or retrieve screws and small parts. For high strength webbings, it results in total fracture of the extensometer arm. A number of methods to retrieve or cushion the extensometer arm were considered with no success. We subsequently developed a procedure to measure elongation using a video camera and gauge marks on the specimen, which was as follows: a 5-inch gauge length is marked on the webbing at a small pre-load tension (1 to 2% of breaking strength). A lightweight paper ruler graduated in 0.1-inch increments is taped at one end to the 0 gauge mark on the webbing using a narrow piece of tape (approximately 0.1 inch). The other end hangs free over the 5-inch gauge mark. The video camera is focused on the lower 5-inch mark, and follows this as the test proceeds. The upper edge of the ruler stays fixed.

As the test runs, the Instron chart is pipped at various load intervals, and simultaneously a statement is made into the microphone input of the video camera. In this way, when the tape is replayed, the load may be read from the chart at the designated pips, and the elongation, at the corresponding time, may be read from the movement of the gauge mark relative to the ruler. The elongation may be estimated to the nearest 0.01 inch from the ruler. With sufficient experience, it is possible to read elongation from the video camera display as the test is running, without using the tape replay. When necessary, the tape is replayed for the final point to accurately determine elongation at break and match it to the corresponding load at break from the Instron chart. This method was used on all but the very initial low strength webbing tests which were done with the extensometer. A duplicate run using both methods was conducted on one webbing type to assure the test validity, with good results.

Tensile testing in the original state, as well as after all of the following treatments, was conducted by this procedure. Values are reported at break for tensile strength, elongation, and energy absorption (area under the curve). Unless otherwise noted, all results presented are an average of 5 values.

6. Accelerated Weathering

The procedure used was changed from FED-STD-191A, Test Method 5804 [7] to ASTM Test Method D2565-79 [8], according to contract modification P00001. The reason for the change is to obtain better correspondence with exposure to sunlight, which we assume is the degradative agent which it is desired to simulate, and, therefore, more reliable comparisons between fibers and weaves.

The attached spectral distribution curves are copies from literature provided by the Atlas Company, manufacturers of the Weatherometer. Method 5804 specifies the use of a "Sunshine Carbon Arc," the spectral distribution curve for which is compared to normal sunlight in Figure 1. Note that the carbon arc emission contains a large energy peak in the 350-450 nm region, while the curve for sunlight shows only a gradual rise through this wavelength range. The DuPont Technical Bulletin X-189 "Light Resistance of Industrial Fiber Products" [9] says "... the primary cause for light degradation of fibers is ultraviolet rays with wavelengths between 290 and 400 nm." Consequently, they caution that "For comparative testing of fibers, the spectral distribution in the ultraviolet portion of the radiation should be as close as possible to that encountered in actual use of the fiber products. This is important because the relative rate of degradation of fibers varies considerably with spectral distribution, and erroneous conclusions could be drawn even though the fibers receive the same total ultraviolet radiation during the test." They further say "DuPont believes that the carbon arc is not an acceptable substitute for outdoor exposure since no consistent correlation either with outdoor exposure tests or with actual weathering performances has been observed by DuPont."

For many years there has been a better source than the carbon arc for simulating sunlight exposure, namely the Xenon arc lamp. Its spectral distribution is given in Figure 2 and can be seen to match that of sunlight very closely, except for two small peaks between 450 and 500 nm, a region which does not seriously degrade most textile fibers. It is this Xenon lamp which is specified in ASTM Method D2565-79 for exposure of plastic specimens.

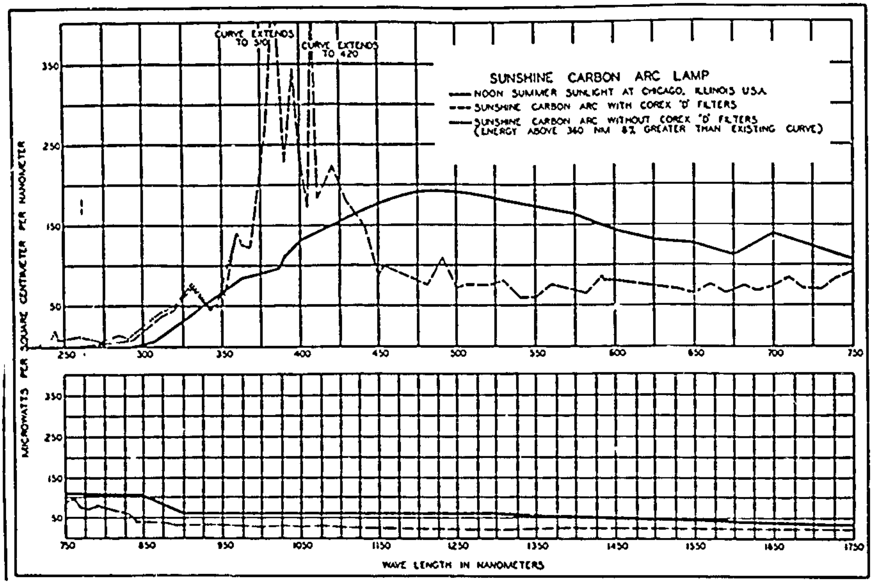

Figure 1. Spectral Distribution of Sunshine Carbon Arc

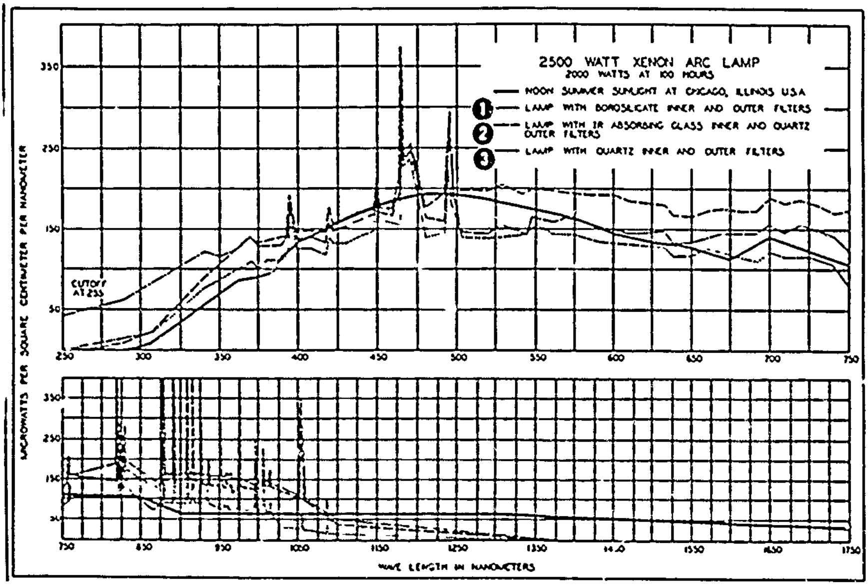

Figure 2. Spectral Distribution of Xenon Arc Lamp

The specific procedures, within the guidelines of ASTM D2565-79, which we used are as follows: Procedure A for comparative evaluation within a series exposed simultaneously in one instrument. For the best comparison, we ran identical shuttle and shuttleless constructions side by side. The total specimen length used was 54 in., as required for subsequent tensile testing by Federal Standard 191A, Test Method 4108. At least 8 in. of specimen in the central section of the webbing was exposed to the weathering conditions. The remaining specimen length was wrapped around the test rack and secured in the back by means of a plastic buckle.

ASTM D2565-79 (Section 4.3) states thickness at the start and end of the test shall be recorded. As initial thickness has previously been determined, and is fixed by the specification, and final thickness was not the property of interest, we chose to omit this step.

Specimen mounting was over the entire length of the test rack, and comparison samples were alternated in position around the rack diameter. Specimen positions were not rotated during the 200 hour exposure. The test rack, however, rotated continuously.

The Weatherometer was a Type AH. The bulb was a Xenon arc with Borosilicate inner and outer filters. The filters and burners were pre-aged by the manufacturer in accordance with ASTM D2565-79. The inner filter was changed at least every 300 hours and the outer filter at the time the bulb was changed (at least every 1500 hours).

Wattage settings for each exposure interval were adjusted according to the recommendations of the equipment supplier.

The black panel temperature was 145°±5°F. Spray water was deionized and filtered to <20 ppm total solids. The light and spray cycle consisted of 102 minutes of light without spray and 18 minutes of light with spray.

The relative humidity conditions, as a result of the showering sequence, were in the range of 35 to 40% RH immediately prior to the spray cycle.

7. Hex Bar Abrasion

Webbings were abraded 2500 cycles in a hex bar abrader according to FED-STD-191A, Test Method 5309 [10]. The rods used for testing were obtained from the Narrow Fabric Institute, Inc. The quality of the first shipment of rods was unacceptable, according to the description within the Standard. The quality of a replacement shipment was still not ideal, as there was scale deposited on some faces. However, as this represented the best available, we used these rods after carefully cleaning the surface with fine emery paper. As noted in the test method, two new edges were used for each abrasion test.

8. High Speed Impact

Testing was conducted on an apparatus available at the Aero-Mechanical Engineering Directorate at the Natick RD&E Center. This tester is a high capacity compressive impact device which Albany International Research Co.

(then Fabric Research Laboratories) built for Natick about 20 years ago. This device consists of two steel carriages mounted on a track structure, and propelled toward each other by pneumatic pistons. When the device is used for compression testing, the specimen is mounted on the front face of one carriage, the carriages are accelerated by pneumatic cylinders, and then coast freely towards a collision at the center of the track span, compressing the specimen on impact.

For the tensile impacts of the current study, one carriage is removed from action, and the tensile specimen is secured, by means of heavy capstan jaws, as a tether between the active carriage and the stationary end of the track. The specimen is impacted in tension when the movable carriage is propelled down the track, pulling the webbing taut and bringing the carriage to a stop. The magnitude of the tensile impact depends on the kinetic energy of the carriage, and is controlled by varying either the mass or the velocity of the carriages, or both. To provide impact velocities at relevant levels, the original heavy compression carriages had to be replaced with a new lightweight carriage structure, designed and fabricated for this program. The resultant carriage weight was varied from 116 to 226 lbs, and the impact velocities ranged from 15 to 25 ft/sec. The parachutes that use the webbings tested in this study are generally designed to be deployed at relatively low speeds, of the order of 250 ft/sec or less. However, this is an extremely high speed for tensile cycling. The velocities described above still provide for a fairly high rate of speed, without the construction of expensive specialized equipment.

With this apparatus, the webbings were subjected to 5 cycles to 50% of their breaking energy, as determined by original slow-speed tensile testing, then removed from the tester and returned to the laboratory for subsequent slow-speed tensile testing to break, as described in Section III,5. While this approach does not permit actual measurement of breaking strength, elongation or energy absorption at high speed, it does, however, detect any damage which might have been caused by the high speed cycling which subsequently affects the tensile properties measured at standard testing speeds.

9. Edge Abrasion

A test device for edge abrasion of webbings was designed as part of this contract. The test device, shown in Figure 3, consists of a motor driven belt sander mounted in stand so that the belt surface runs horizontal. Five webbings are clamped between two steel plates (5 in. x 2-5/8 in.), with the webbing edges carefully aligned, and protruding from the plates by approximately 3/8 in. The total normal force, applied from the weight of the plates and clamps, is 1070 gm (2.4 lb). The sander frame is designed so that the webbing and clamp assembly is lowered down onto the belt, parallel to the belt axis, through an alignment slot. No additional normal force is applied. To minimize variations from sander startup, the sander is running prior to lowering the webbing.

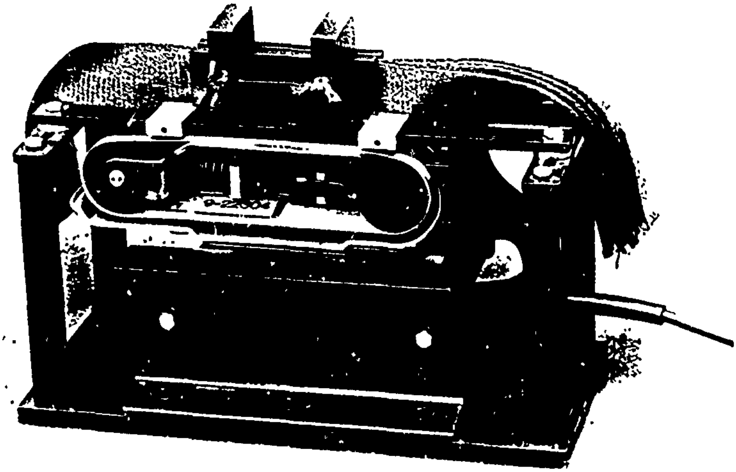

Figure 3. Edge Abrasion Test Device

Each webbing edge is abraded for 30 seconds in one direction followed by 30 seconds in the other direction (parallel and anti-parallel to the belt) for a total of one minute per side. The second side is abraded in the same manner. This abrasion time was selected by experiment such that some observable damage resulted, but not such severe degradation as would obviously remove a webbing from service. The abrading surface is repositioned or changed every two to three tests to maintain a fresh surface. Prior to tensile testing, a visual assessment is made of the number of yarns abraded from each side. This is a rather qualitative measurement as it is sometimes difficult to determine the exact number, and the number may vary slightly from one webbing to another, or one spot to another. Values ranged from 1 to 4 yarns. For shuttleless webbings, two values are given; the first for the non-catch-cord edge, and the second for the catch-cord edge.

IV. RESULTS AND DISCUSSION

1. Thickness

All webbing types, including the polyester constructions, are within specification limits. The results, along with specification limits, are shown in Table 2. The minimum thickness limit on the resin coated samples has been determined from the minimum uncoated specification value less 12%. The values for the polyester webbings are in agreement with the stated goal of attaining specification thickness by the substitution of 1000-denier polyester for the normal 840-denier nylon.

2. Weight

Results and specification limits are shown in Table 3. The maximum weight specification for the resin coated samples has been determined as the maximum uncoated value +10%. Several of the polyester shuttleless constructions are slightly higher than the allowed specifications (from 1 to 10% higher). In all cases, even those within spec, the polyester webbings are heavier than the corresponding nylon 6,6 constructions, in most cases by approximately 10 to 20%.

3. Lateral Curvature

Results are shown in Table 4. All uncoated webbing measurements are within specification. While no specification is given for the resin coated samples, these were also tested and are well below the maximum value for uncoated samples.

4. Webbing Construction

Ends/warp, binder, and picks/inch were checked for all uncoated webbings. (Note: In shuttleless weaving, one filling insertion lays in two yarns, which have beer counted as 2 picks). The results are given in Table 5. The nylon 6,6 and nylon 6 webbings are all within specification. The polyester webbings, however, are all low in picks/inch (from 5 to 27% below spec for the shuttle constructions and from 11 to 36% below specifications for the shuttleless). In one case (Type XIX, shuttleless polyester), the end count was also 12% below spec. The polyester webbings were constructed to meet thickness and weight specifications, with the required ends/warp used, and then the maximum possible number of picks inserted. Even with the reduced pick count, the filling ply used for the shuttle polyester webbings had to be reduced to a single ply, which, according to specifications should only be used in shuttleless webbings where two picks are inserted per shed. The yarn ply data are given in Table 6. Since development of optimized polyester constructions was not the objective of this work, we accepted these webbings for the required comparative testing. The construction results on these polyester webbings imply that a straight 1000-denier substitution for 840-denier nylon is not the ideal approach. Nevertheless, these results do not mean that a polyester webbing cannot be made to meet all performance specifications with some small changes in construction, thickness, or weight. Clearly, additional construction development is necessary to utilize the polyester properties appropriately.

TABLE 2. Webbing Thickness (in) (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6		Nylon 6		Polyester	
			SH	SL	SH	SL	SH	SL
VI	none	0.03 -0.05	0.041	0.042	0.042	0.042	0.042	0.046
	resin	0.026-0.05	0.042	0.041	0.042	0.042	0.043	0.049
VIII	none	0.04 -0.07	0.049	0.049	0.050	0.049	0.048	0.053
	resin	0.035-0.07	0.048	0.050	0.049	0.049	0.051	0.056
X	none	0.105-0.140	0.108	0.110	0.115	0.112	0.123	0.121
	resin	0.092-0.140	0.100	0.110	0.111	0.111	0.120	0.127
XIII	none	0.08 -0.12	0.085	0.083	0.086	0.084	0.095	0.096
	resin	0.07 -0.12	0.084	0.084	0.086	0.083	0.091	0.101
XIX	none	0.10 -0.13	0.106	0.102	0.105	0.102	0.104	0.107
	resin	0.088-0.13	0.105	0.109	0.107	0.111	0.106	0.106
XXII	none	0.09 -0.12	0.104	0.105	0.101	0.097	0.106	0.113
	resin	0.079-0.12	0.104	0.104	0.103	0.101	0.109	0.115

SH - Shuttle SL - Shuttleless
*Resin coated minimum = uncoated minimum - 12%.

TABLE 3. Webbing Weight (oz/yd) (average of 5 values)

Webbing Type	Treatment	Spec* (Max)	Nylon 6,6		Nylon 6		Polyester	
			SH	SL	SH	SL	SH	SL
VI	none	1.15	1.06	1.06	1.09	1.13	1.12	1.26**
	resin	1.26	1.08	1.06	1.07	1.11	1.14	1.32**
VIII	none	1.60	1.40	1.42	1.43	1.41	1.50	1.61**
	resin	1.76	1.37	1.40	1.40	1.40	1.57	1.67
X	none	3.70	3.22	3.33	3.35	3.34	3.68	3.70
	resin	4.07	3.22	3.34	3.34	3.32	3.75	3.81
XIII	none	2.90	2.38	2.43	2.48	2.44	2.70	2.93**
	resin	3.19	2.38	2.42	2.45	2.44	2.78	3.04
XIX	none	4.10	3.13	3.24	3.17	3.27	3.74	3.42
	resin	4.51	3.17	3.26	3.19	3.29	3.89	3.48
XXII	none	3.50	3.02	3.06	2.96	2.96	3.43	3.52**
	resin	3.85	3.02	3.06	3.08	3.03	3.53	3.62

SH = Shuttle SL = Shuttleless
*Resin coated minimum = uncoated minimum + 10%.
**Off-Spec

TABLE 4. Lateral Curvature (32nds in) (average of 5 values)

Webbing Type	Treatment	Spec (Max)	Nylon 6,6		Nylon 6		Polyester	
			SH	SL	SH	SL	SH	SL
VI	none	8	0	1	0	3	1	0
	resin		2	1	0	0	0	0
VIII	none	8	0	0	1	1	1	1
	resin		1	0	0	0	0	0
X	none	8	0	0	0	0	0	1
	resin		0	0	0	0	1	0
XIII	none	8	0	0	1	0	1	0
	resin		0	0	0	0	0	0
XIX	none	8	0	0	0	1	0	0
	resin		0	1	0	1	0	0
XXII	none	8	0	0	0	0	1	0
	resin		1	1	0	0	0	0

SH = Shuttle SL = Shuttleless

TABLE 5. Construction (ends/warp)/Binder (picks/inch)

Webbing			Nylon 6,6		Nylon 6		Polyester	
Type	Treatment	Spec	SH	SL*	SH	SL*	SH	SL*
VI	none	114/-/21	114/-/22	114/-/44	114/-/22	114/-/46	114/-/20**	114/-/36**
	resin							
VIII	none	166/-/18	166/-/18	166/-/36	166/-/19	166/-/37	165/-/15**	166/-/26**
	resin							
X	none	257/31/22	258/31/22	257/31/48	257/31/24	257/31/48	257/31/16**	257/31/27**
	resin							
XIII	none	281/34/24	284/34/24	282/34/52	277/34/26	281/34/52	282/32/18**	281/34/40**
	resin							
XIX	none	280/-/18	282/-/18	280/-/40	280/-/20	280/-/40	280/-/14**	246/-/32**
	resin							
XXII	none	259/-/18	264/-/18	264-/36	259/-/19	259/-/36	259/-/14**	259/-/23**
	resin							

SH - Shuttle SL - Shuttleless
*Picks/inch should be twice the spec for shuttleless webbings.
**Off-Spec

TABLE 6. Yarn Ply (warp/binder/fill)

Webbing Type	Treatment	Spec*	Nylon 6,6 SH	Nylon 6,6 SL	Nylon 6 SH	Nylon 6 SL	Polyester SH	Polyester SL
VI	none	2/-/2	2/-/2	2/-/1	2/-/2	2/-/1	2/-/1**	2/-/1
	resin							
VIII	none	2/-/2	2/-/2	2/-/1	2/-/2	2/-/1	2/-/1**	2/-/1
	resin							
X	none	3/1/2	3/1/2	3/1/1	3/1/2	3/1/1	3/1/1**	3/1/1
	resin							
XIII	none	2/1/2	2/1/2	2/1/1	2/1/2	2/1/1	2/1/1**	2/1/1
	resin							
XIX	none	3/-/2	3/-/2	3/-/1	3/-/2	3/-/1	3/-/1**	3/-/1
	resin							
XXII	none	3/-/2	3/-/2	3/-/1	3/-/2	3/-/1	3/-/1**	3/-/1
	resin							

SH = Shuttle SL = Shuttleless
*Fill ply should be 1 for shuttleless webbings
**Off-Spec

Samples of the three yarns used for the webbings were checked for denier value. The 2-ply nylon 6,6 (2 x 840 = 1680 denier) was measured as 1719 denier. The nylon 6 (1680 denier) was measured as 1711 denier. Both of these are only a 2% difference from nominal denier, and judged insignificant. The plied polyester of two 1000-denier strands was measured as 2274, which is 14% over the desired 2000 denier. One reason for this significant difference is that the polyester was yarn-dyed and tested in the dyed state. Yarn shrinkage during dyeing resulted in the observed denier increase. The nylon 6,6 and nylon 6 denier tests were performed on undyed samples, which were subsequently piece-dyed in the finished webbing. Yarn-dyeing is allowed in the specifications, and was used for the polyester because of unfamiliarity with Thermosol dyeing conditions required for olive drab polyester. Narricot has suggested using either a smaller denier polyester, or specifying piece dyeing to reduce this denier difference, which has contributed to the need for a reduced pick count in the webbing.

5. Original Tensile Testing

Measurements of tensile strength, elongation, and energy absorption on all webbings are given in Tables 7, 8, and 9. Average load-elongation curves of these results are shown in Figures 4 through 75. Also shown for comparison in these figures are the average load-elongation curves for any additional treatments. All strength values are within specification except for three polyester constructions. These are Type VI, shuttleless, resin coated, 41 lb low; Type X, shuttle, uncoated, 1006 lb low; and Type X, shuttle, resin coated, 140 lb low. As discussed in Section IV,4, Webbing Construction, the polyester constructions have not necessarily been optimized, and these strength differences are most likely attributed to the construction, rather than an inherent property of the polyester. Within each material type, there are no significant differences between the shuttle and shuttleless constructions; either is consistently higher in strength.

There is no specification given for elongation. When comparing the values for shuttle and shuttleless constructions in Table 8, there are again no significant differences in elongation between weaving methods. Considering fiber type, the nylon 6 results scatter about the elongations of comparable nylon 6,6 shuttle webbings. The value ranges from 86 to 130% of the nylon 6,6 shuttle constructions, indicating no significant trend for nylon 6. For the polyester constructions, elongation values are all lower than the comparable nylon 6,6 shuttle webbings, in the range of 64 to 92%, with most values falling within 75 to 85% of the nylon 6,6 shuttle webbing. The polyester webbings show a real difference in elongation. However, because the constructions are not optimum, the origin of this difference cannot be clearly attributed to fiber type. Also, the absence of a specification for this value, and the clear understanding of its meaning in relation to actual field use, do not presently indicate this as either an advantage or disadvantage for the polyester webbings.

TABLE 7. Original Tensile Strength (lb) (average of 5 values)

Webbing Type	Treatment	Spec (min)	Nylon 6,6		Nylon 6		Polyester	
			SH	SL	SH	SL	SH	SL
VI	none	2500	3446	3413	3368	3485	3008	2574
	resin	2500	3510	3384	3405	3440	3003	2459*
VIII	none	4000	5118	5234	4932	4915	4617	4561
	resin	4000	5083	5106	4873	5061	4520	4701
X	none	9500	11209	10525	10770	11138	8494*	9963
	resin	9500	11246	11023	11153	11204	9360*	10380
XIII	none	7000	8690	8610	8461	8674	7303	7244
	resin	7000	8948	8703	8446	8752	7479	7019
XIX	none	10000	12732	12446	11930	11340	12124	10213
	resin	10000	12320	12202	11968	11850	11755	10497
XXII	none	9500	11448	11098	10669	11145	9740	10672
	resin	9500	11035	11330	10831	11227	10350	10807

SH = Shuttle SL = Shuttleless
*Off spec

TABLE 8. Original Tensile Elongation (%) (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6		Nylon 6		Polyester	
			SH	SL	SH	SL	SH	SL
VI	none		27.7	28.2	32.1	35.9	24.2	22.4
	resin		28.8	28.6	31.0	31.7	25.1	26.5
VIII	none		31.6	30.6	33.2	32.0	23.1	24.6
	resin		30.3	32.0	34.7	33.5	23.2	25.8
X	none		34.0	31.5	31.9	34.8	22.5	24.1
	resin		34.8	30.9	30.6	33.6	24.6	22.3
XIII	none		28.3	30.6	34.2	35.2	23.9	26.0
	resin		29.6	26.6	32.3	32.7	23.7	25.7
XIX	none		32.1	28.9	27.7	29.6	26.5	25.3
	resin		31.4	28.3	27.0	30.6	25.8	24.3
XXII	none		31.0	30.3	26.7	28.8	24.2	25.2
	resin		29.0	30.8	30.1	30.8	24.8	25.0

SH = Shuttle SL = Shuttleless
*No spec given

TABLE 9. Original Energy Absorption (ft-lb/ft) (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6		Nylon 6		Polyester	
			SH	SL	SH	SL	SH	SL
VI	none		365	361	434	522	309	263
	resin		410	385	440	460	323	281
VIII	none		620	646	707	667	458	461
	resin		647	685	697	753	435	508
X	none		1442	1131	1280	1428	815	1002
	resin		1453	1169	1346	1405	971	909
XIII	none		930	977	1092	1286	735	786
	resin		1059	876	1127	1281	768	735
XIX	none		1687	1393	1224	1191	1259	1041
	resin		1507	1352	1228	1339	1191	1051
XXII	none		1335	1291	1079	1303	965	1083
	resin		1078	1384	1245	1437	1031	1107

SH - Shuttle SL - Shuttleless
*No spec given

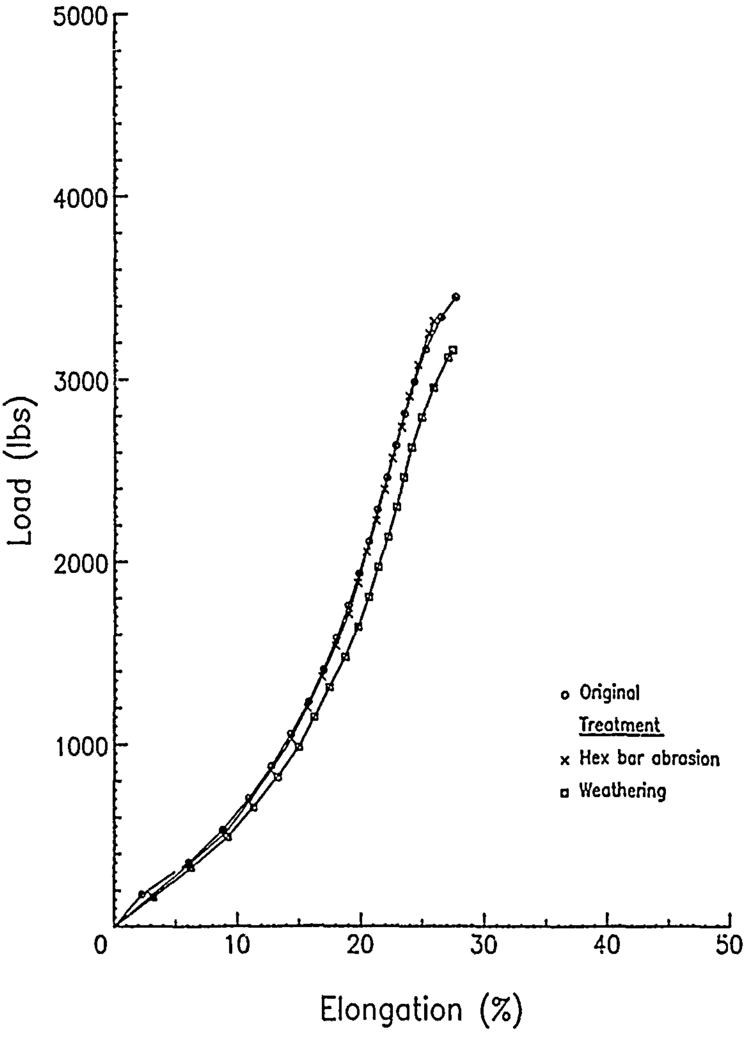

Figure 4. Type 6, Class 1, Uncoated, Nylon 6,6
Original and After Treatment

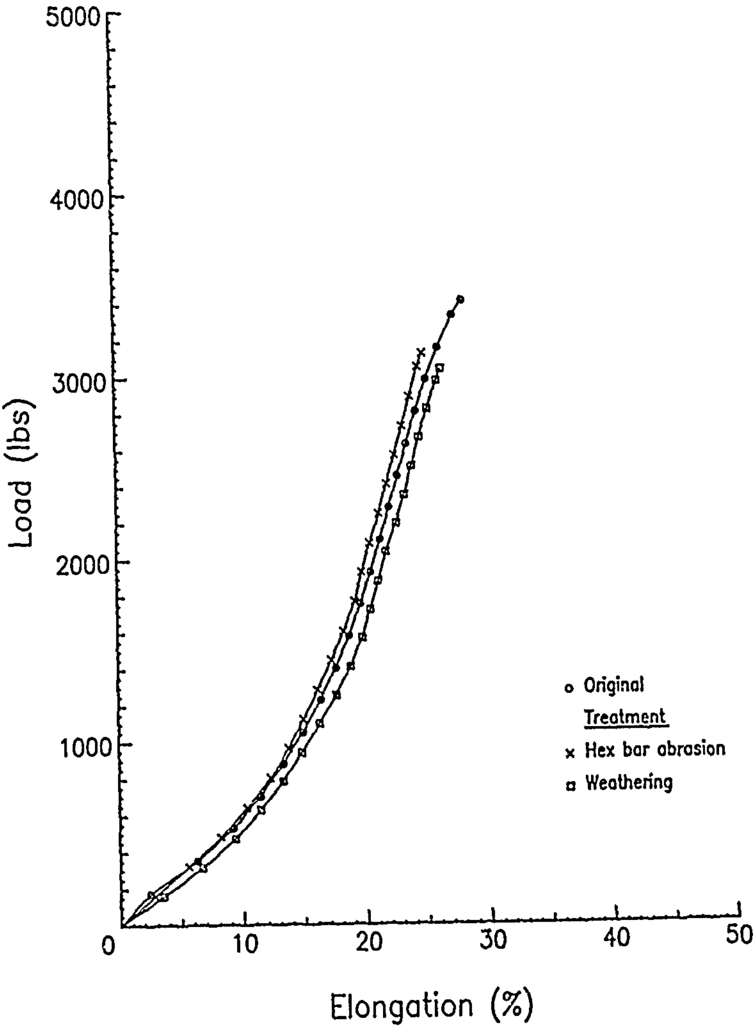

Figure 5. Type 6, Class 2, Uncoated, Nylon 6,6
Original and After Treatment

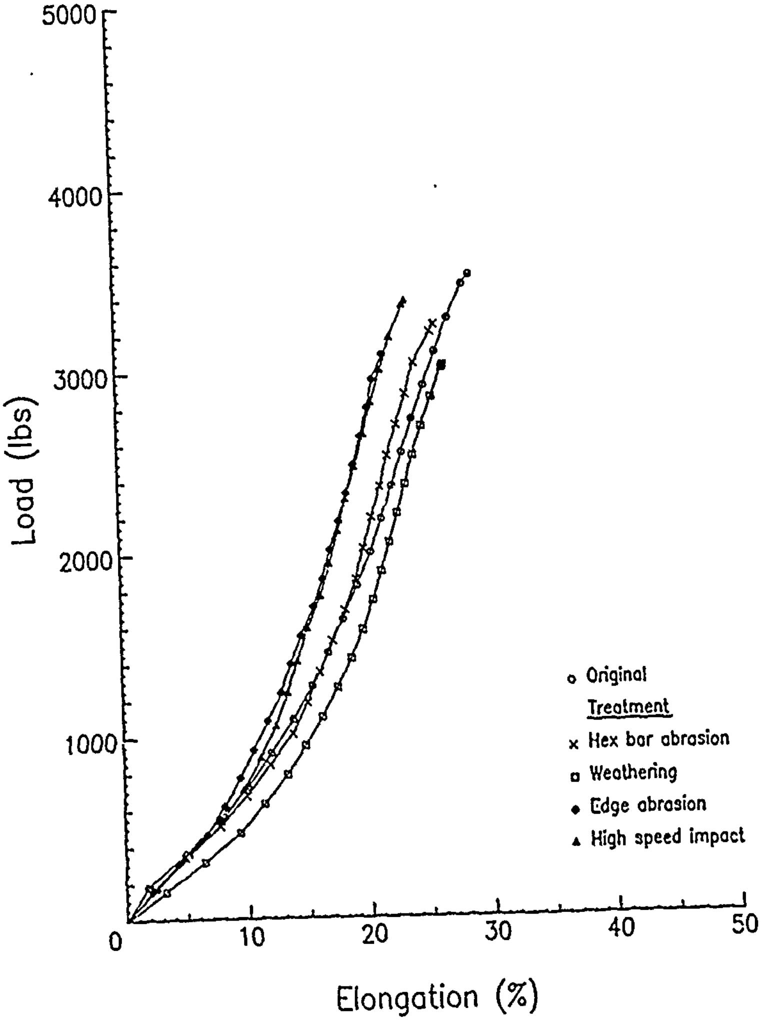

Figure 6. Type 6, Class 1, Coated, Nylon 6,6
Original and After Treatment

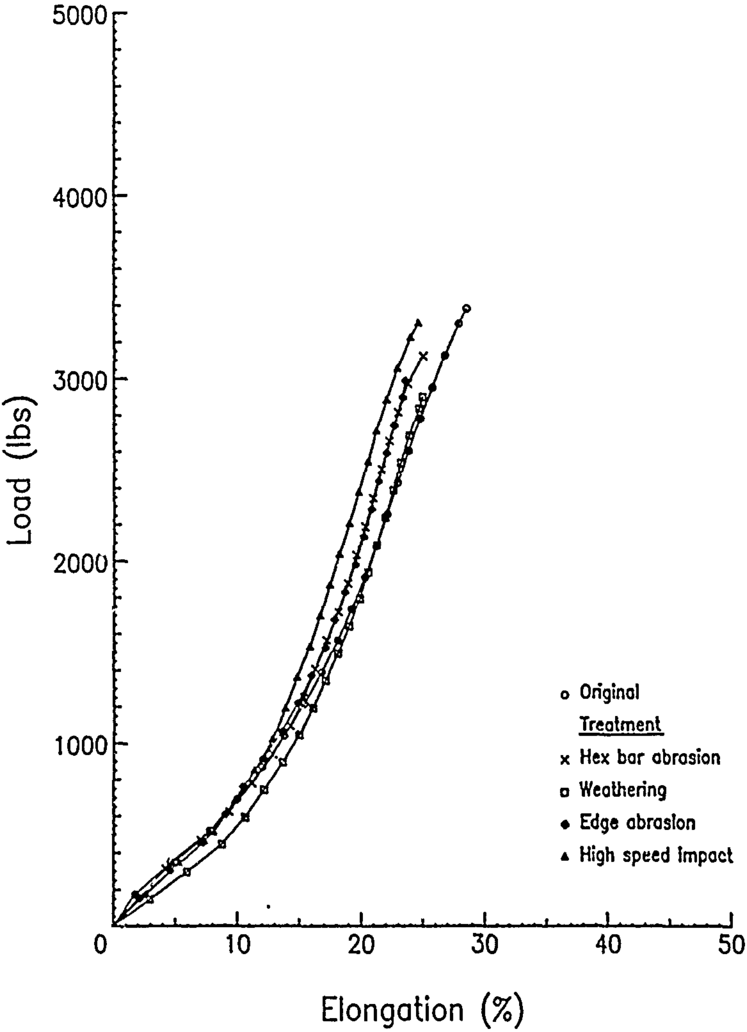

Figure 7. Type 6, Class 2, Coated, Nylon 6,6
Original and After Treatment

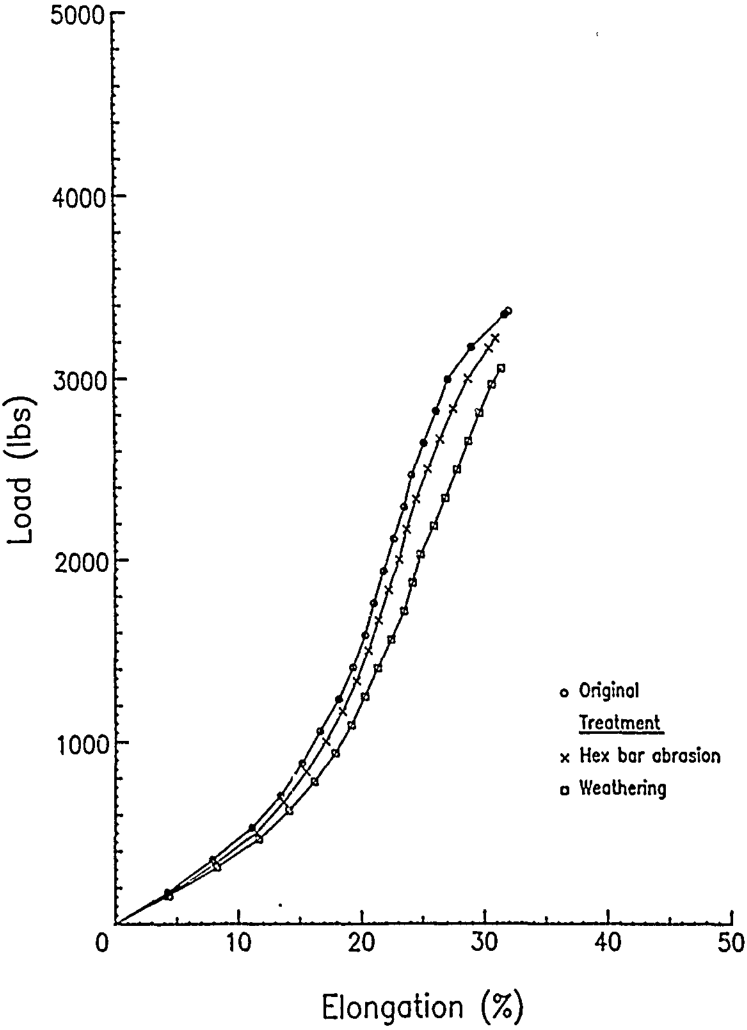

Figure 8. Type 6, Class 1, Uncoated, Nylon 6
Original and After Treatment

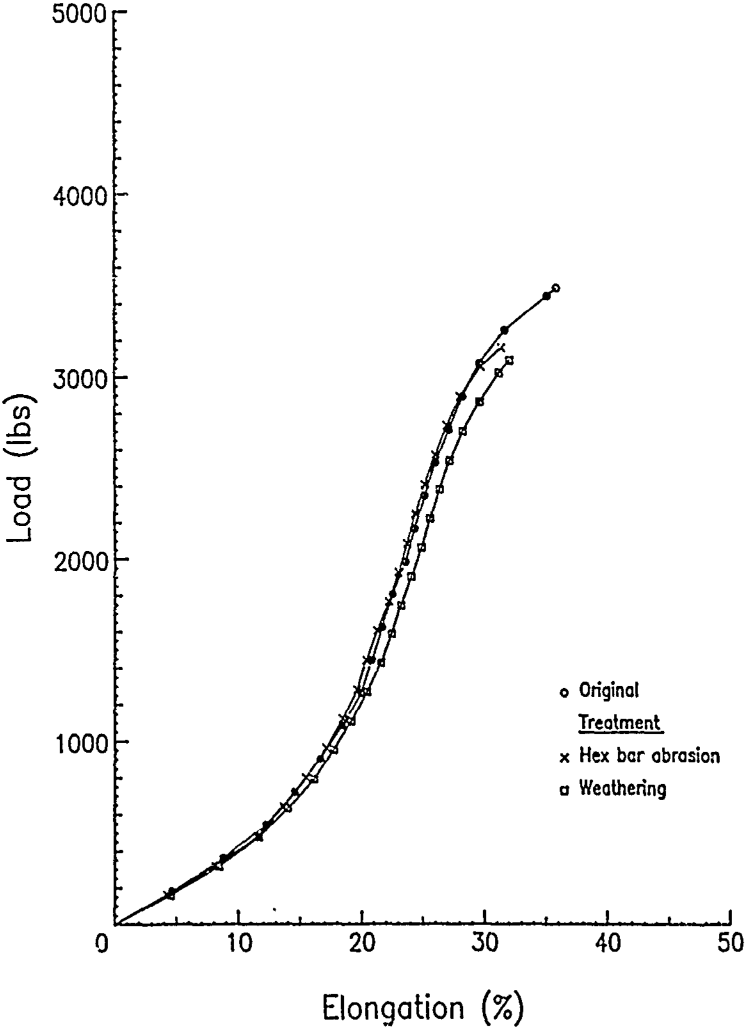

Figure 9. Type 6, Class 2, Uncoated, Nylon 6
Original and After Treatment

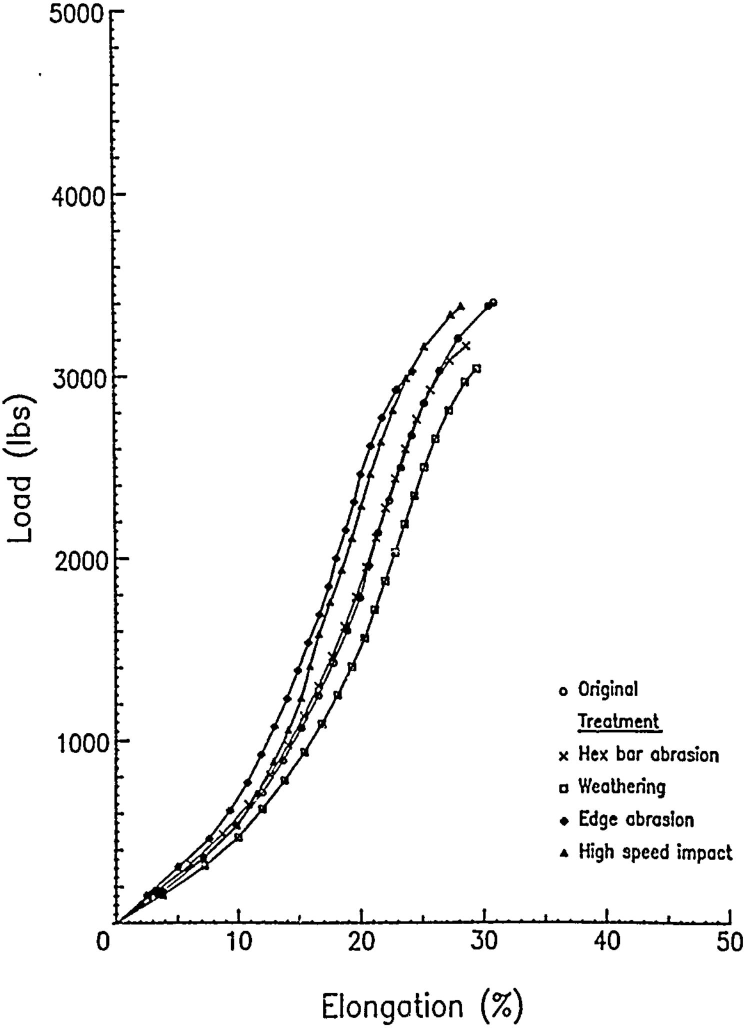

Figure 10. Type 6, Class 1, Coated, Nylon 6
Original and After Treatment

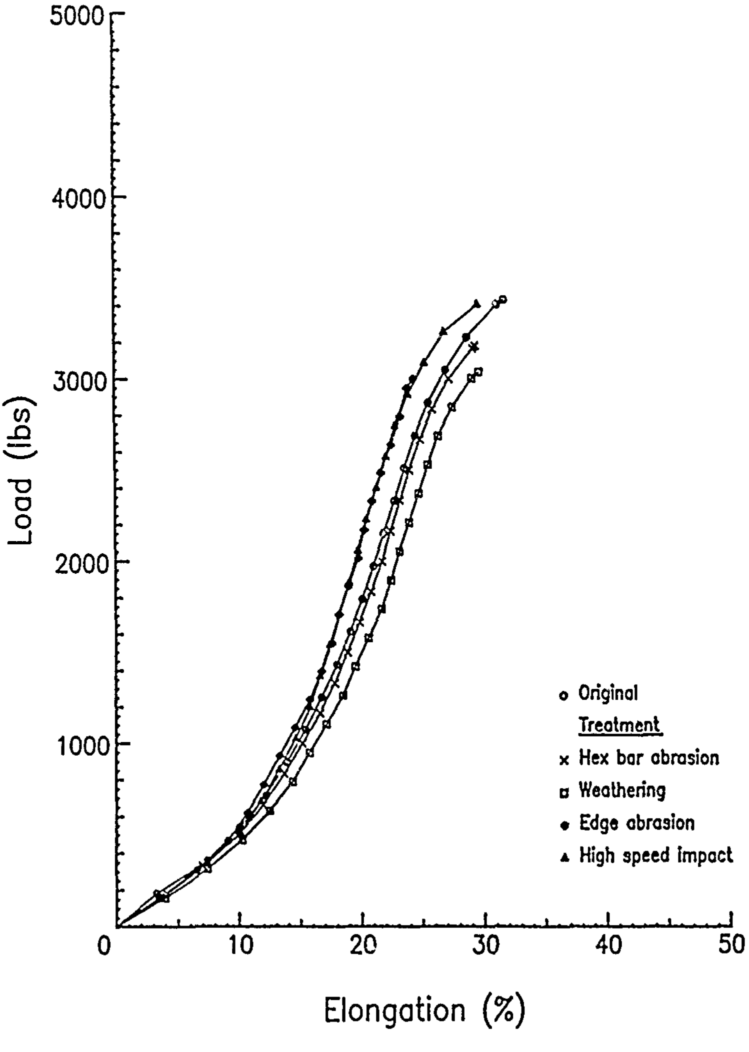

Figure 11. Type 6, Class 2, Coated, Nylon 6
Original and After Treatment

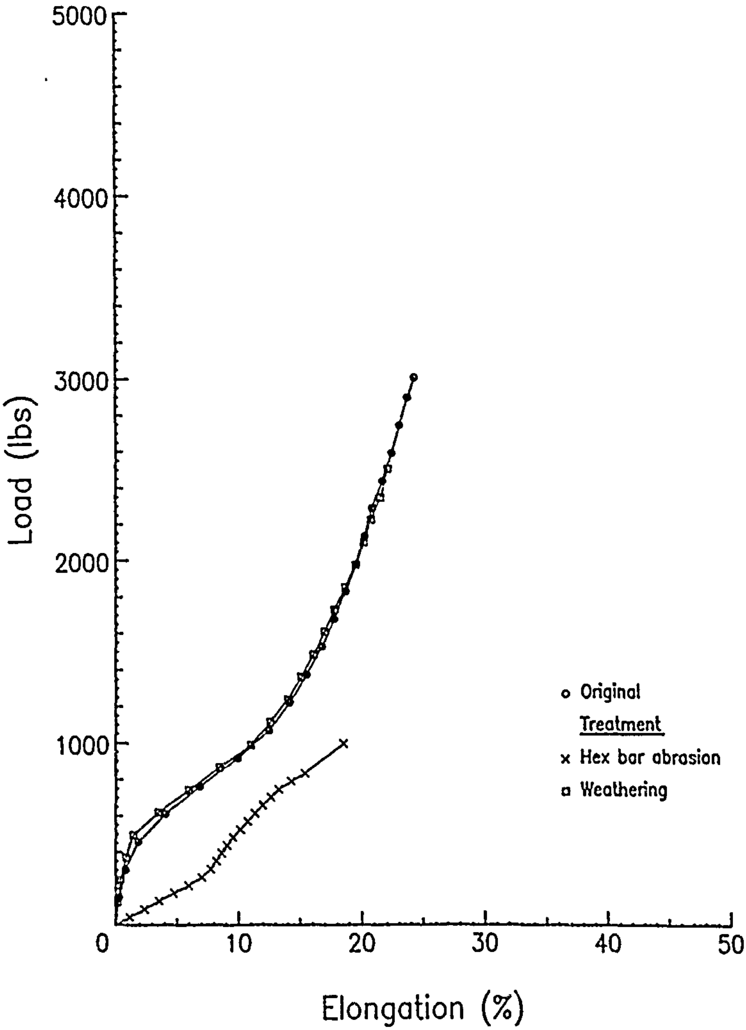

Figure 12. Type 6, Class 1, Uncoated, Polyester
Original and After Treatment

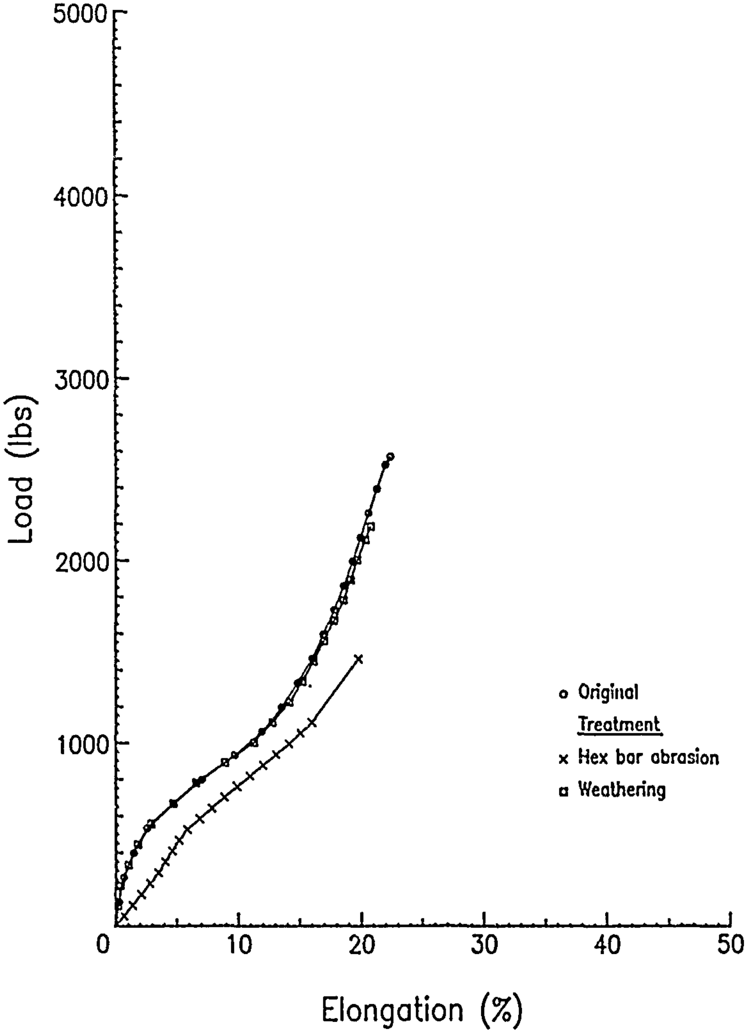

Figure 13. Type 6, Class 2, Uncoated, Polyester
Original and After Treatment

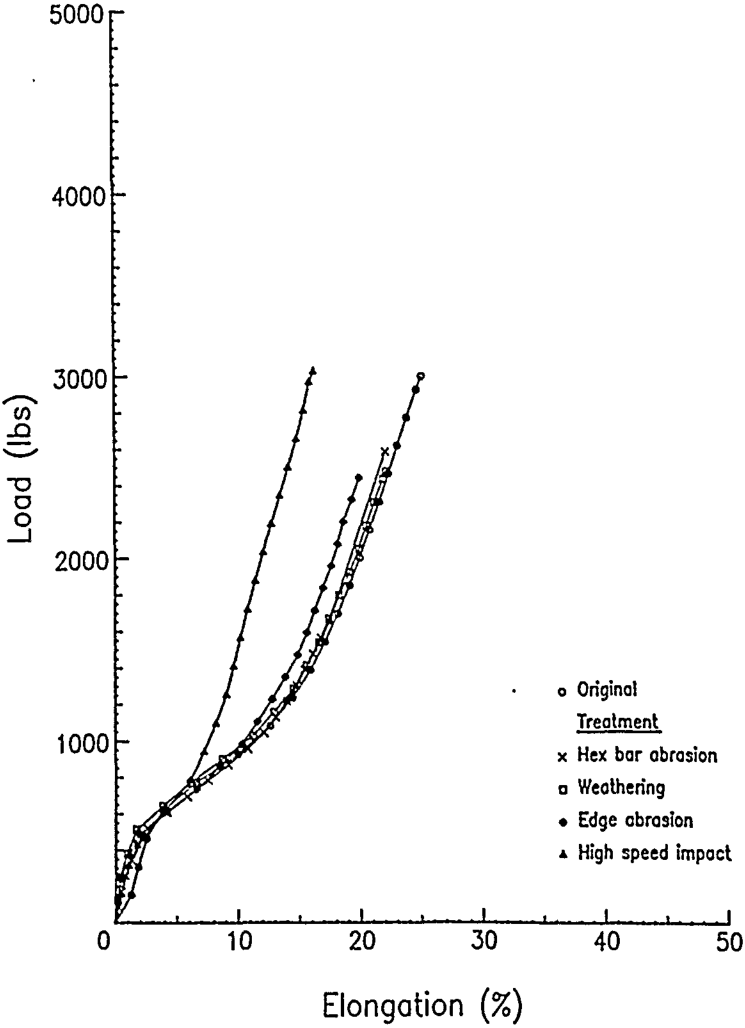

Figure 14. Type 6, Class 1, Coated, Polyester Original and After Treatment

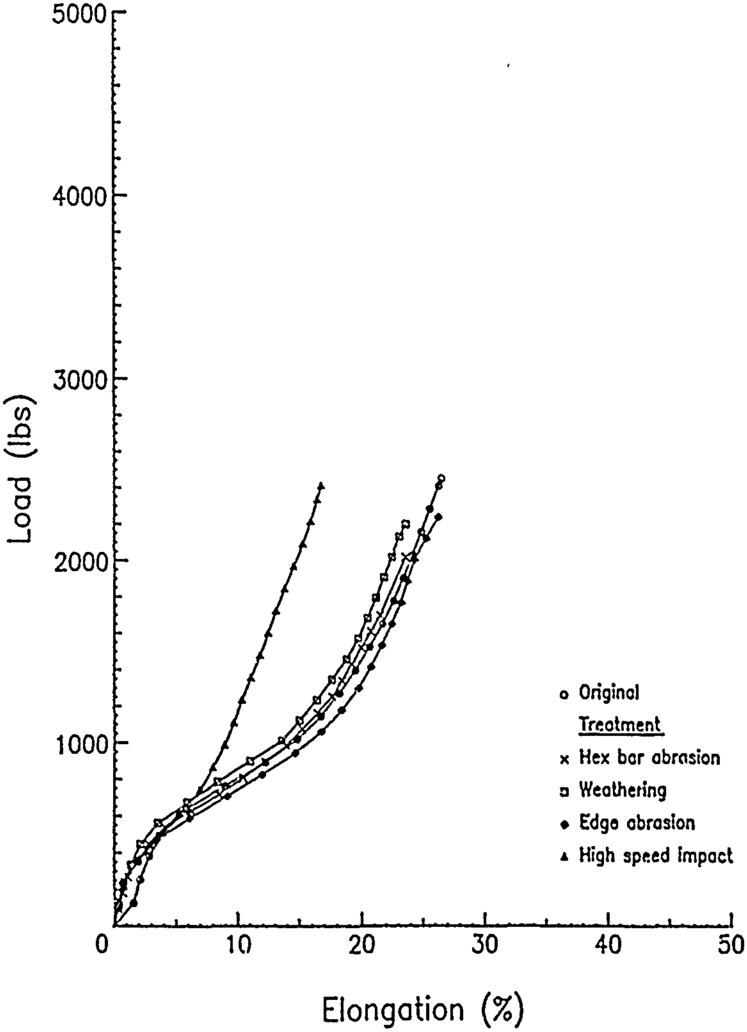

Figure 15. Type 6, Class 2, Coated, Polyester
Original and After Treatment

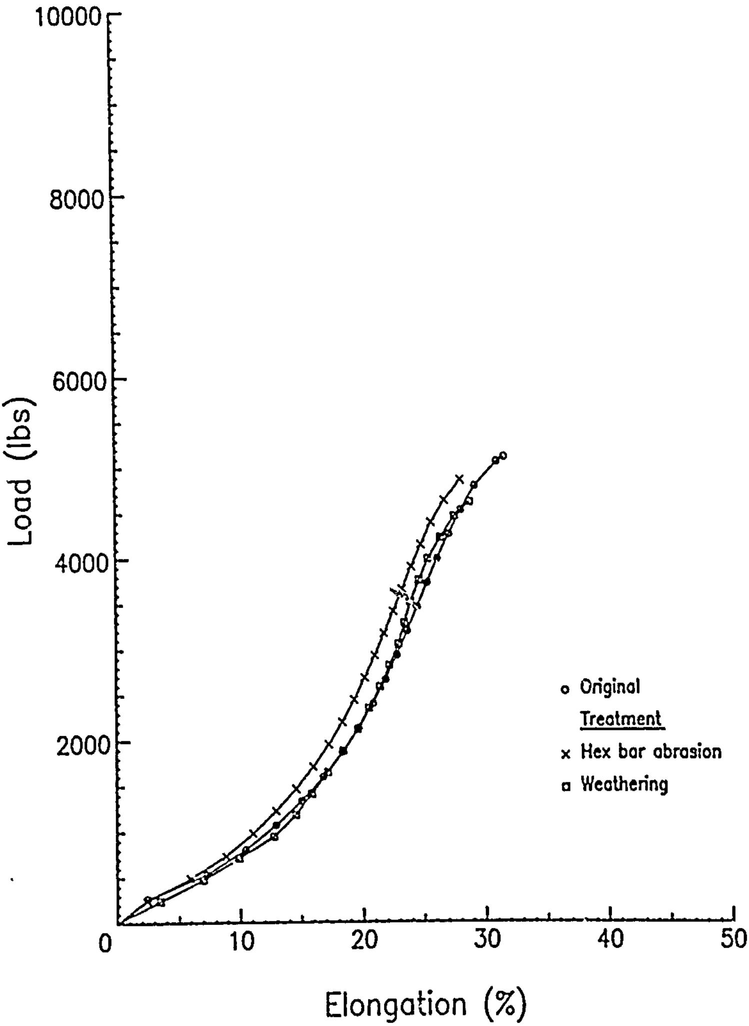

Figure 16. Type 8, Class 1, Uncoated, Nylon 6,6
Original and After Treatment

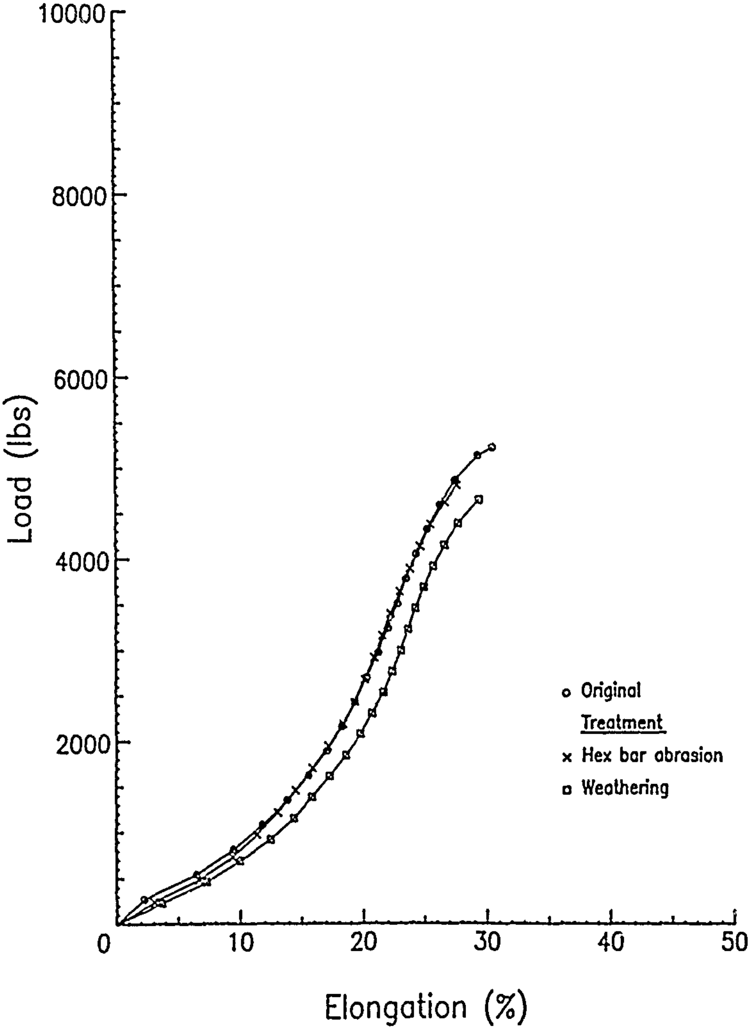

Figure 17. Type 8, Class 2, Uncoated, Nylon 6,6
Original and After Treatment

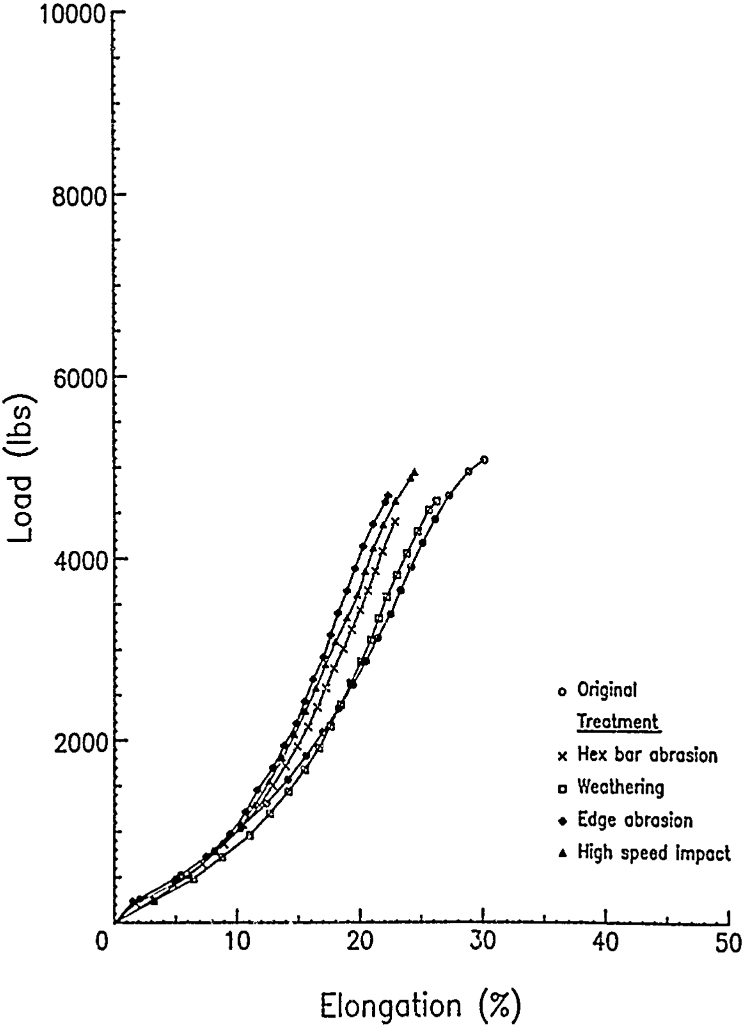

Figure 18. Type 8, Class 1, Coated, Nylon 6,6
Original and After Treatment

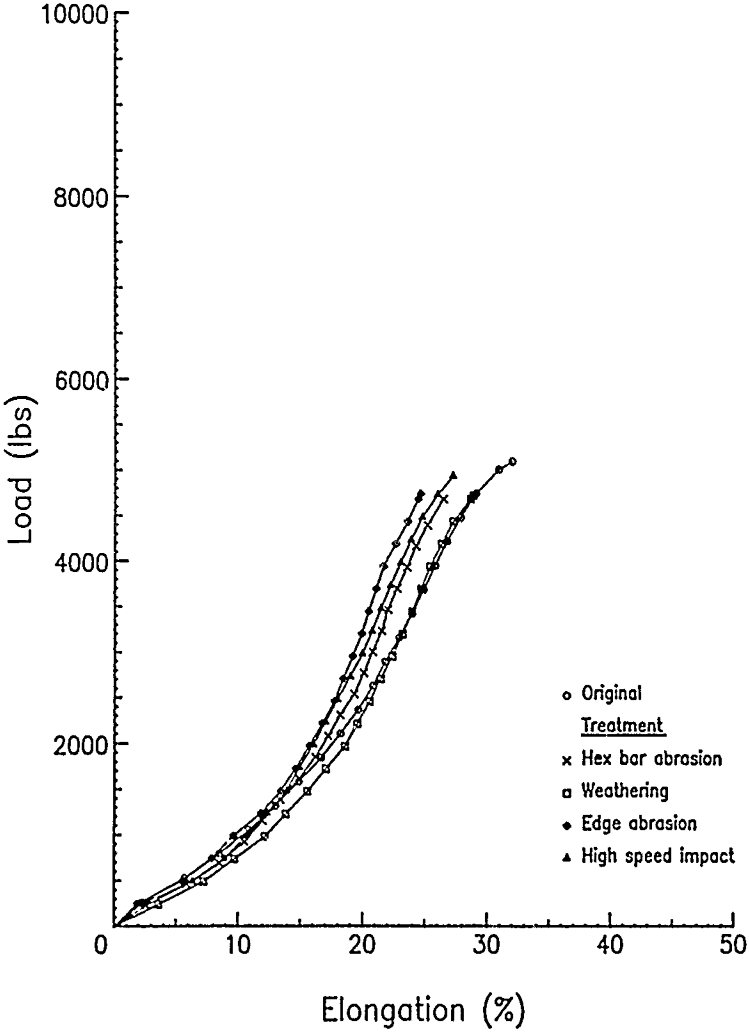

Figure 19. Type 8, Class 2, Coated, Nylon 6,6
Original and After Treatment

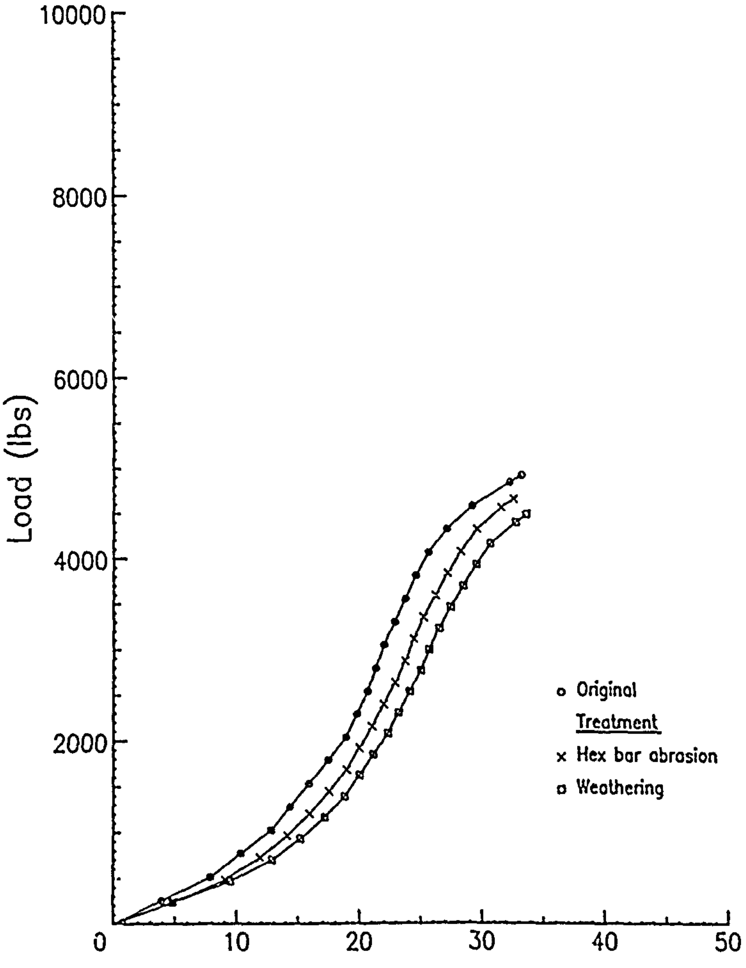

Figure 20. Type 8, Class 1, Uncoated, Nylon 6
Original and After Treatment

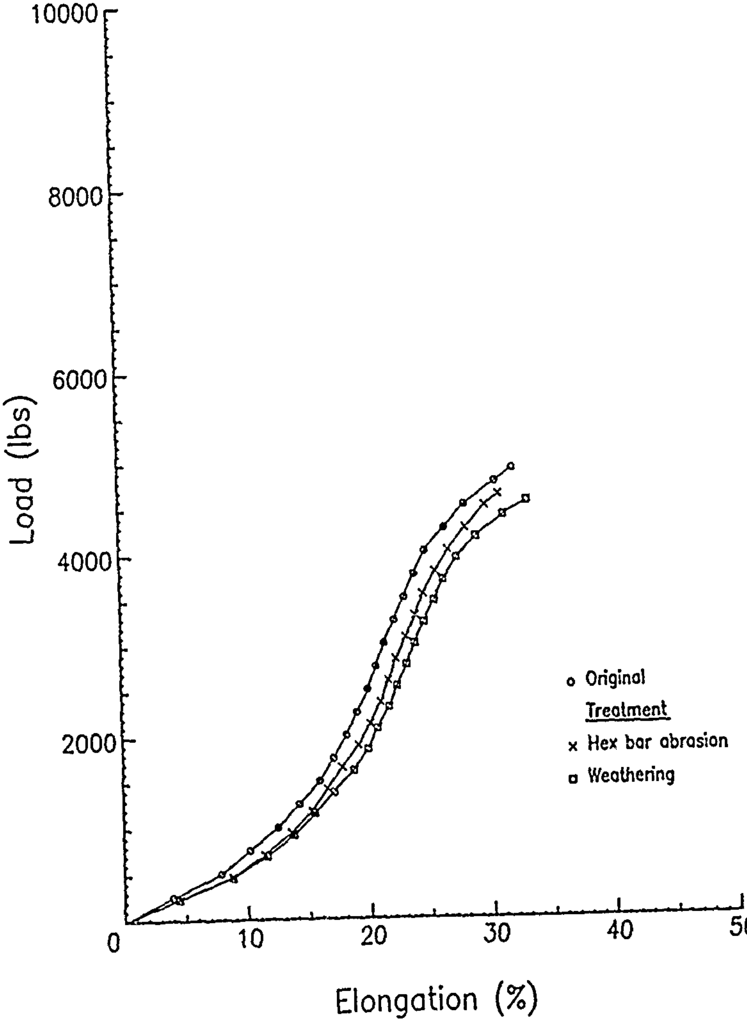

Figure 21. Type 8, Class 2, Uncoated, Nylon 6
Original and After Treatment

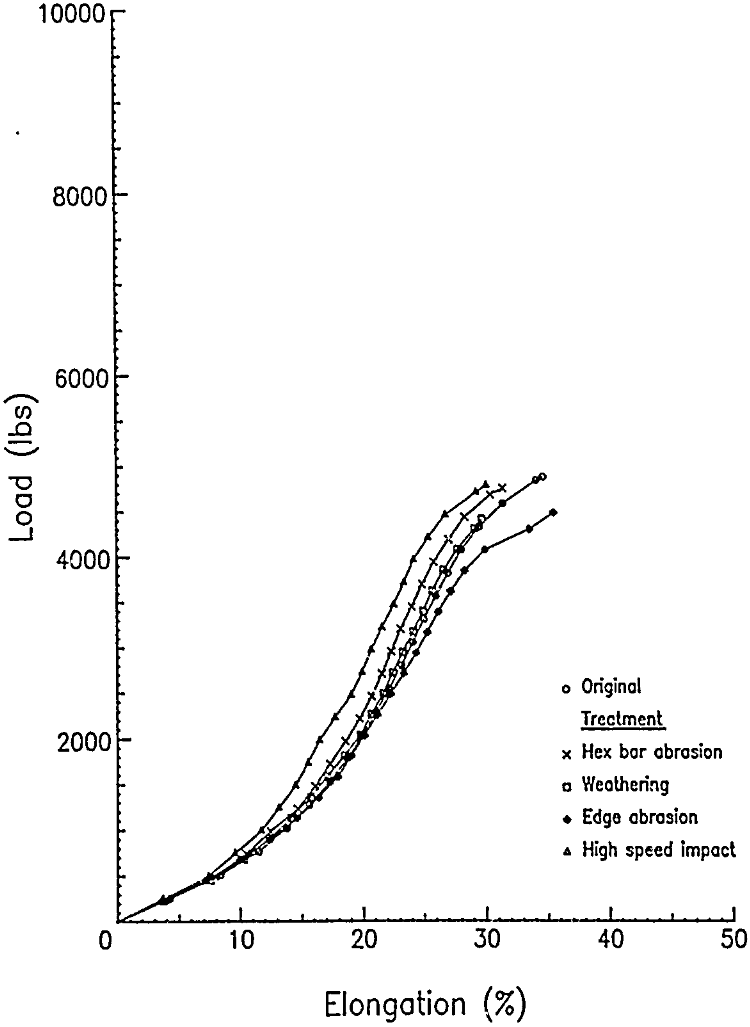

Figure 22. Type 8, Class 1, Coated, Nylon 6
Original and After Treatment

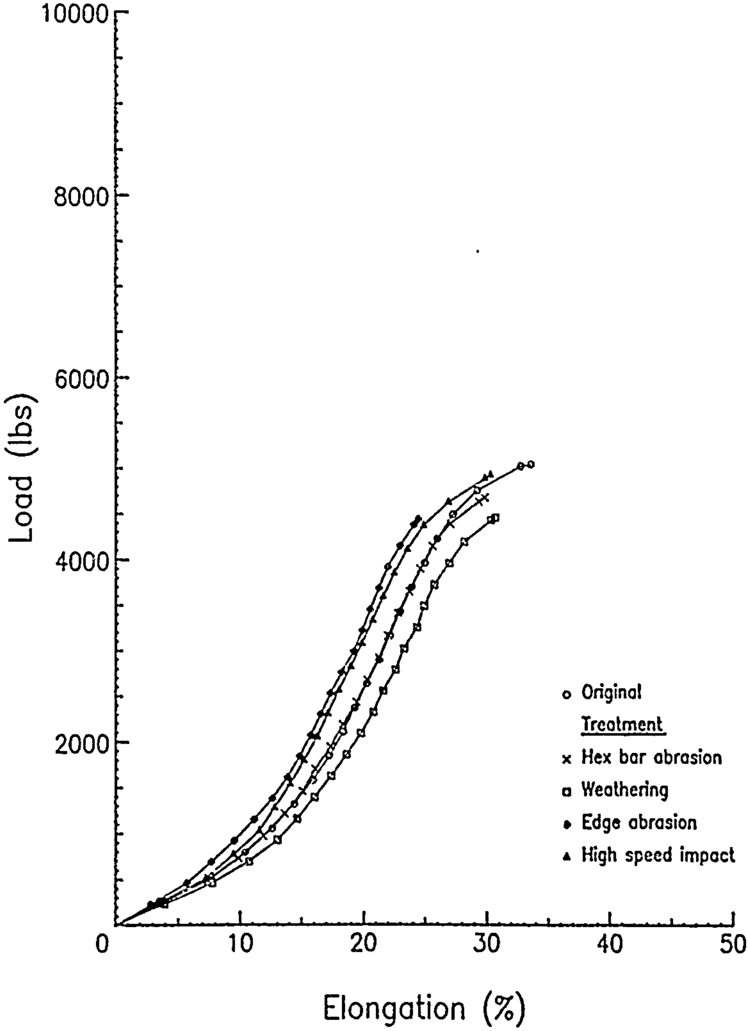

Figure 23. Type 8, Class 2, Coated, Nylon 6
Original and After Treatment

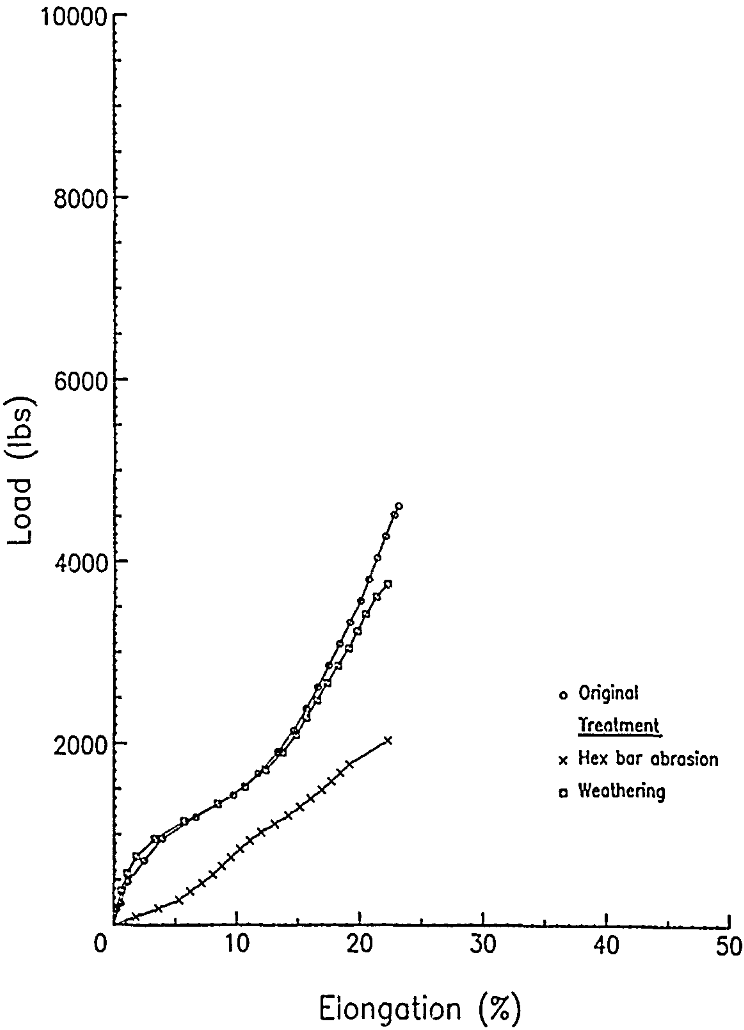

Figure 24. Type 8, Class 1, Uncoated, Polyester
Original and After Treatment

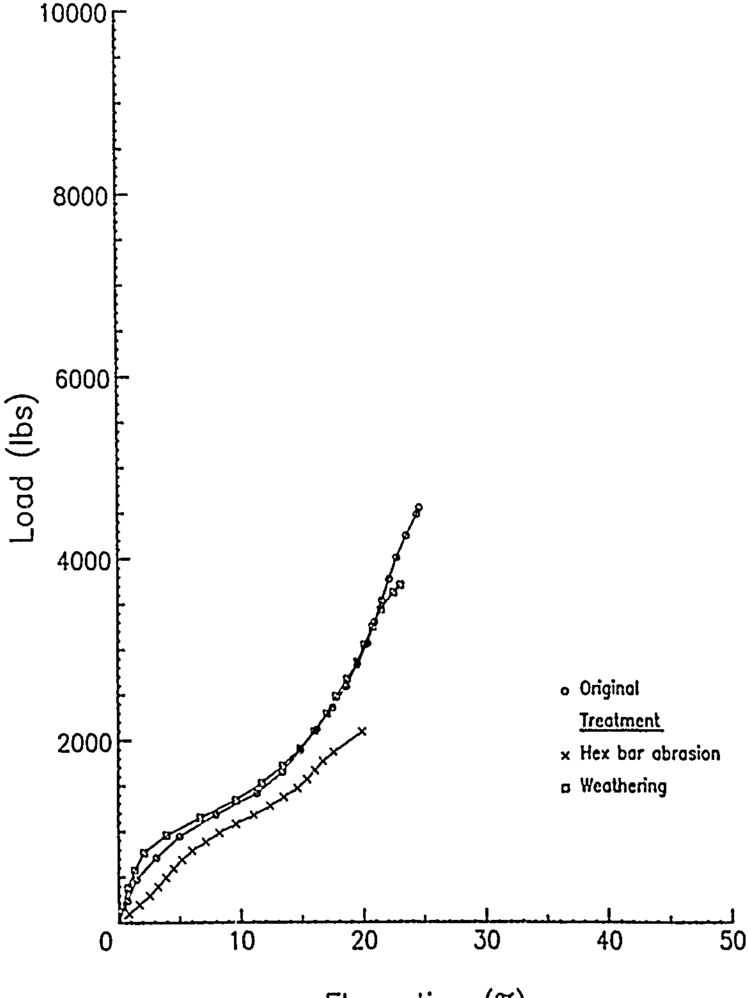

Figure 25. Type 8, Class 2, Uncoated, Polyester
Original and After Treatment

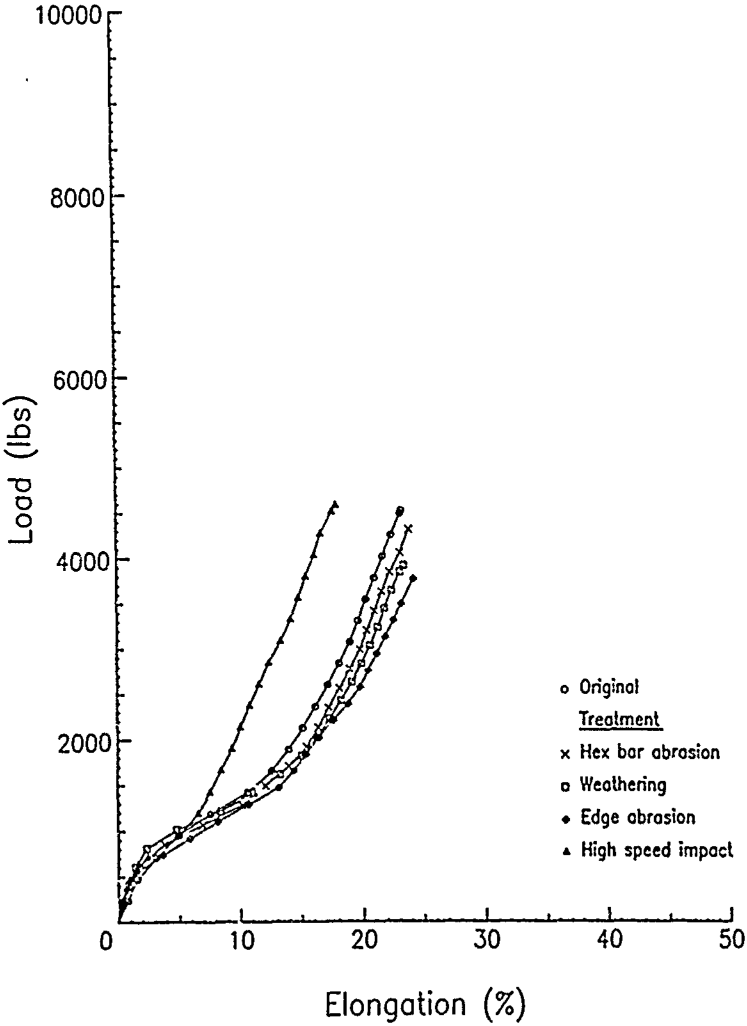

Figure 26. Type 8, Class 1, Coated, Polyester
Original and After Treatment

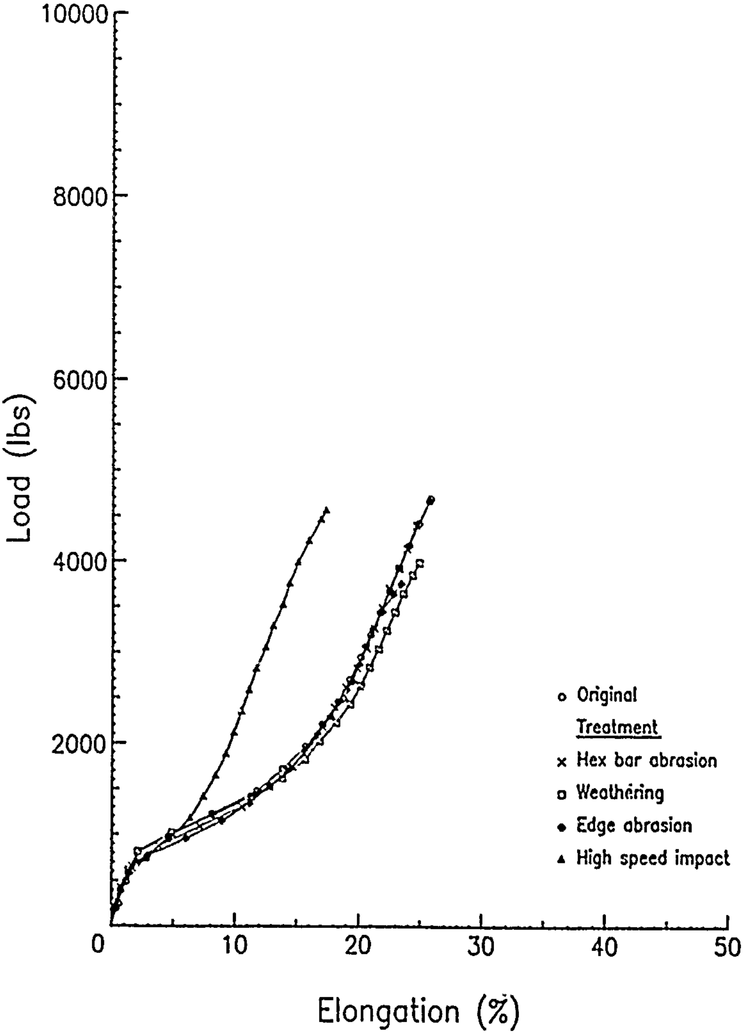

Figure 27. Type 8, Class 2, Coated, Polyester Original and After Treatment

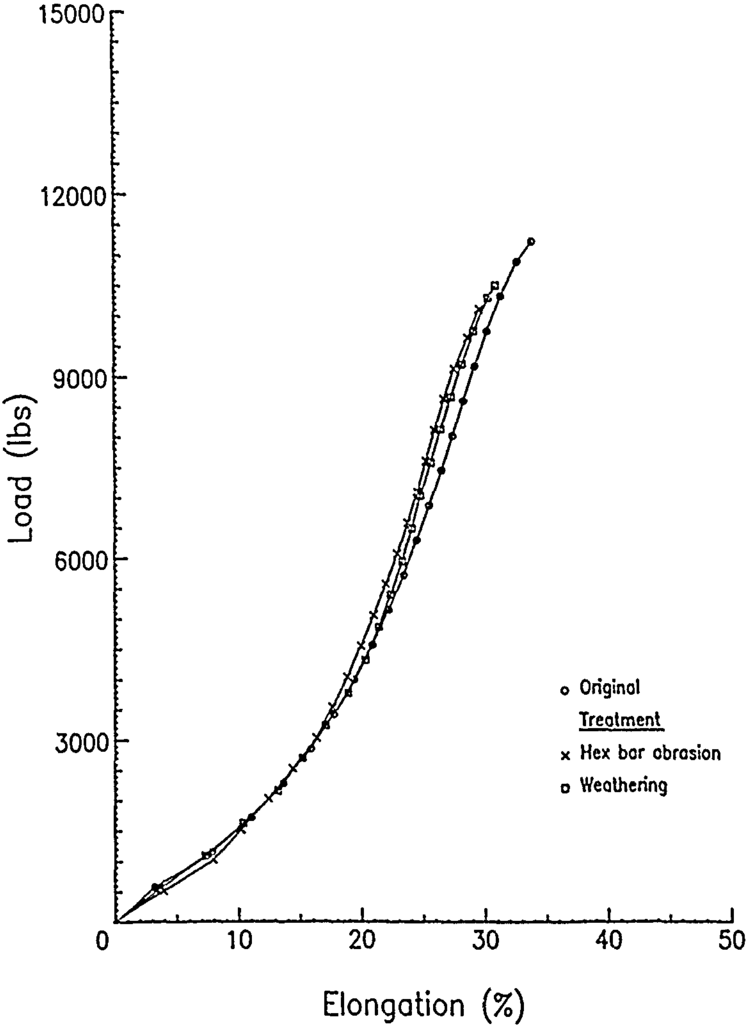

Figure 28. Type 10, Class 1, Uncoated, Nylon 6,6
Original and After Treatment

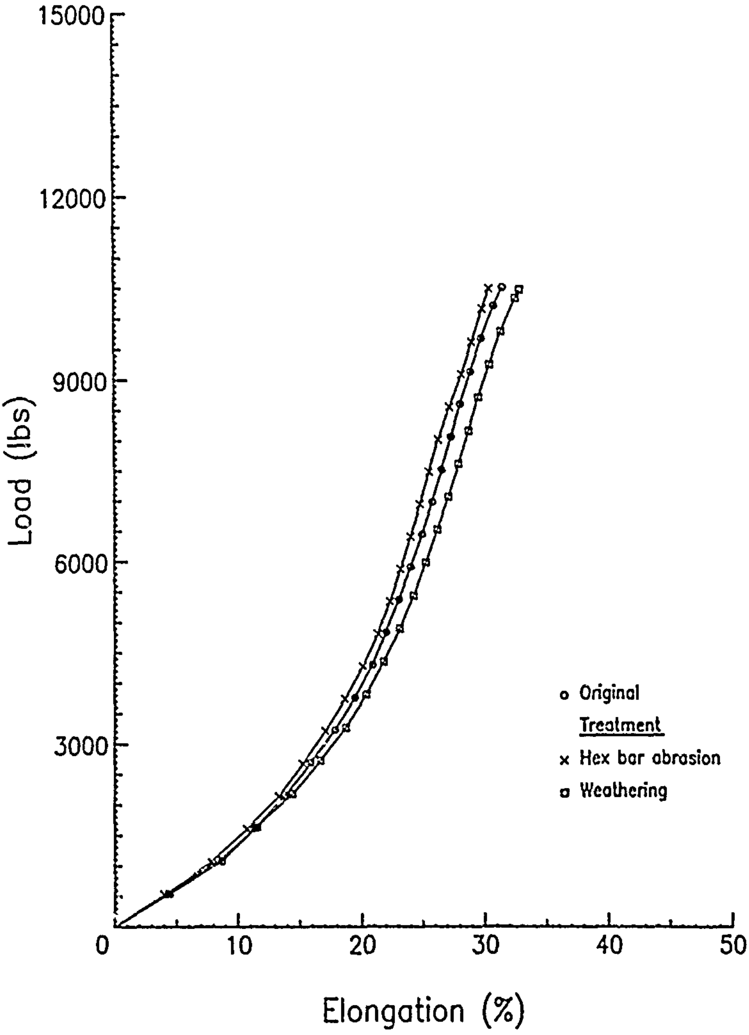

Figure 29. Type 10, Class 2, Uncoated, Nylon 6.6
Original and After Treatment

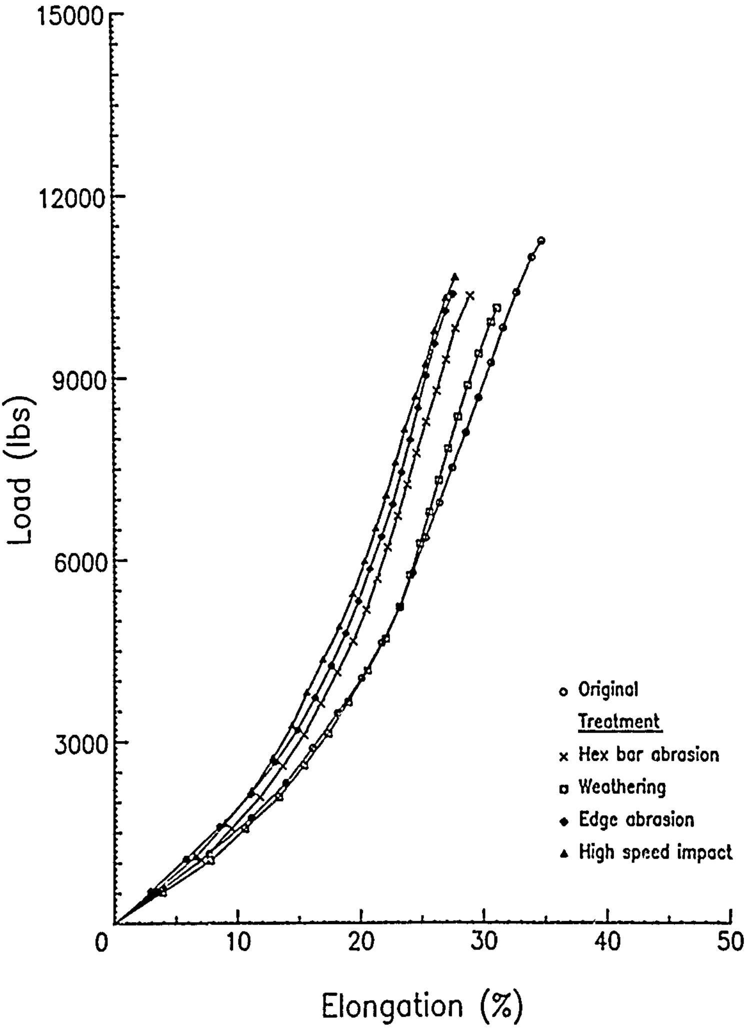

Figure 30. Type 10, Class 1, Coated, Nylon 6,6
Original and After Treatment

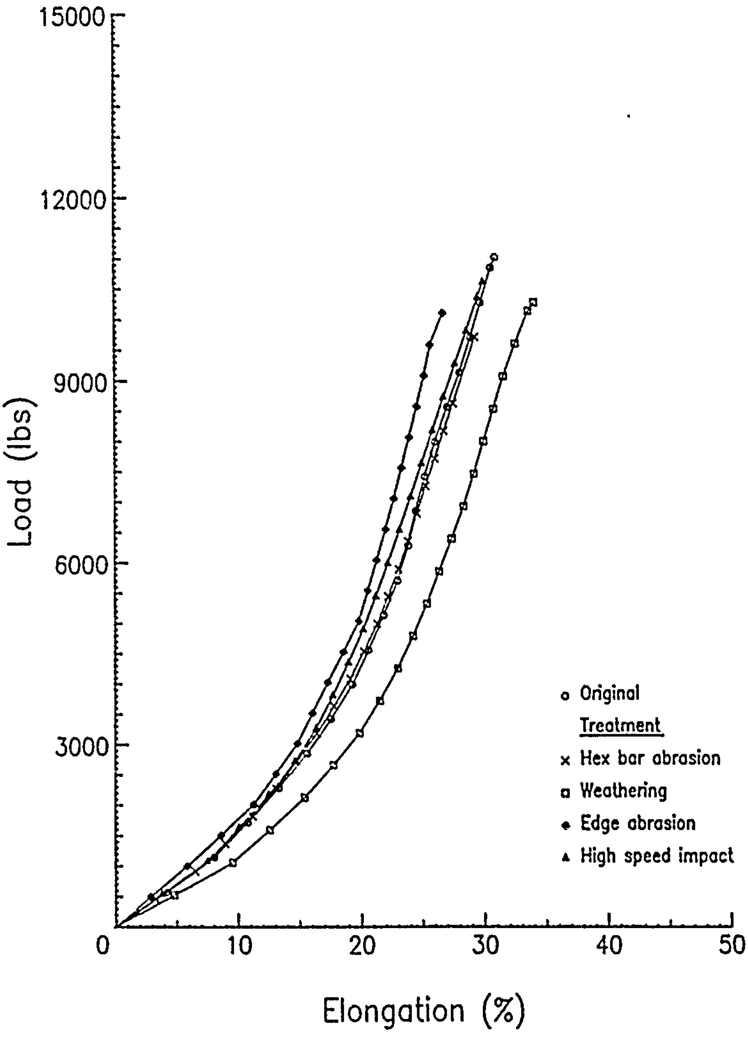

Figure 31. Type 10, Class 2, Coated, Nylon 6,6
Original and After Treatment

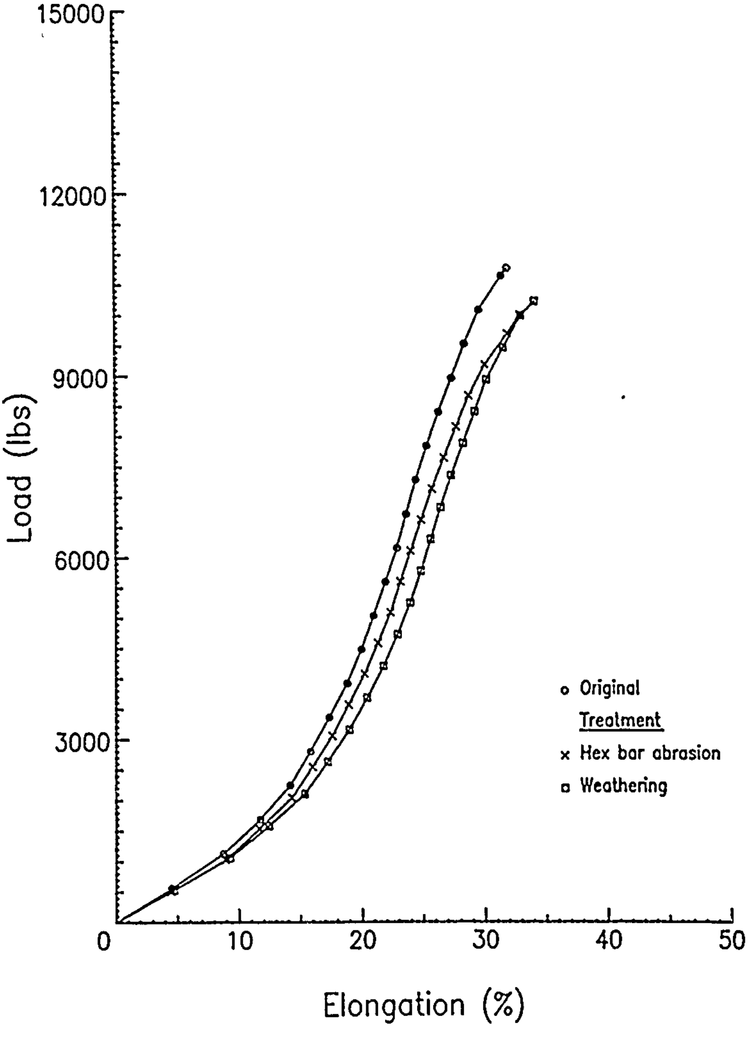

Figure 32. Type 10, Class 1, Uncoated, Nylon 6
Original and After Treatment

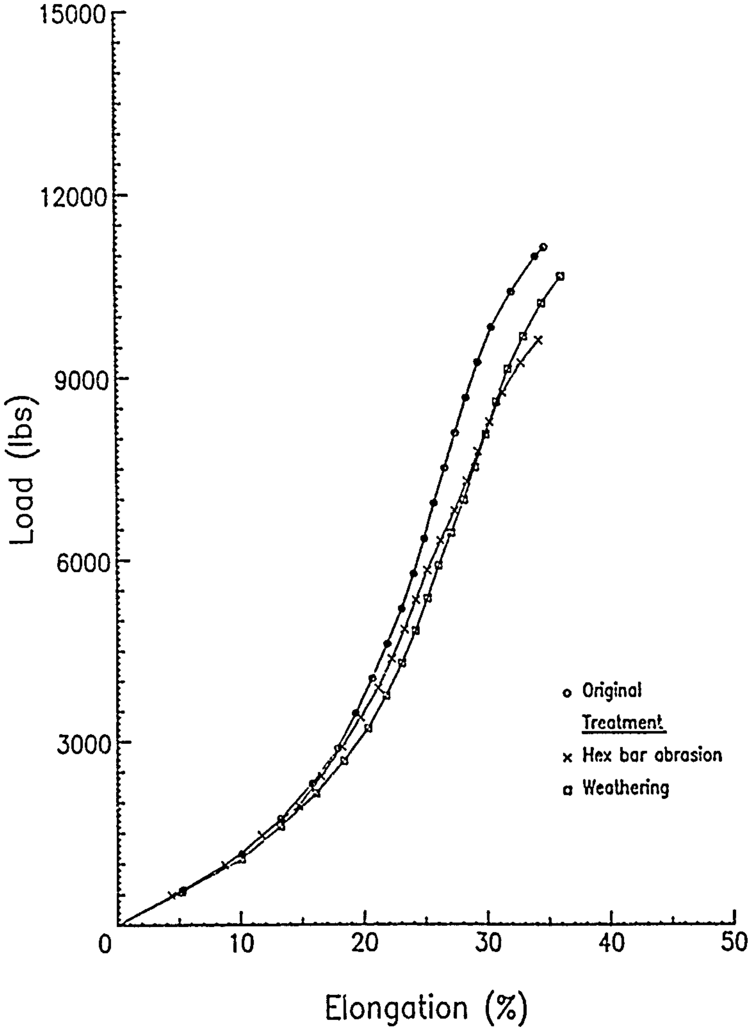

Figure 33. Type 10, Class 2, Uncoated, Nylon 6
Original and After Treatment

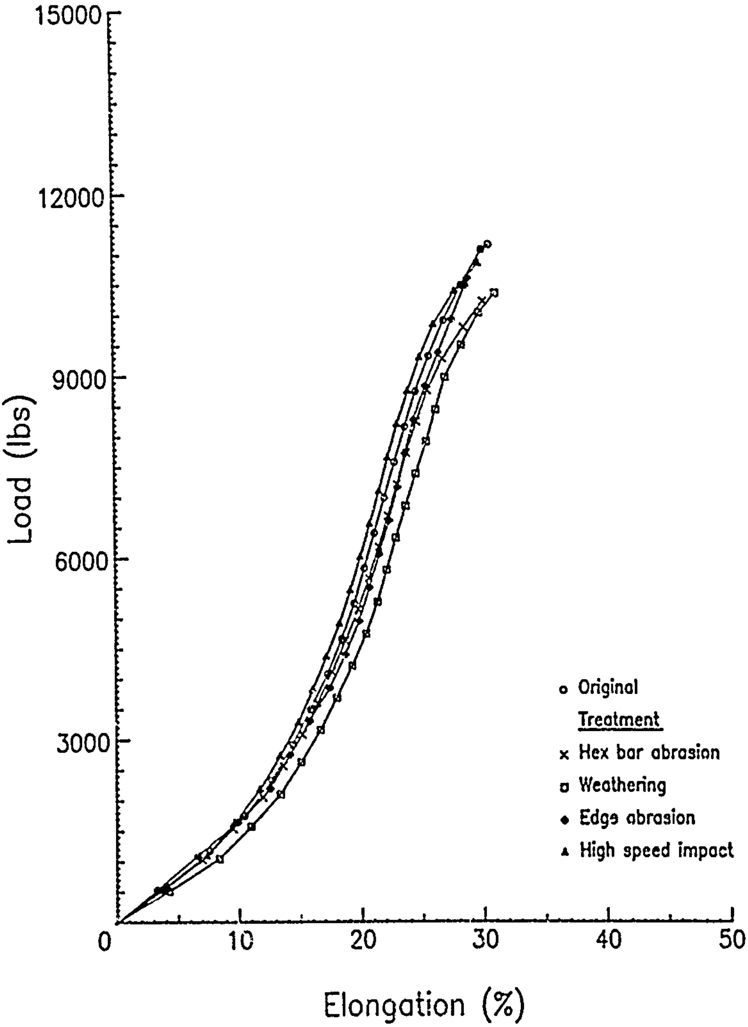

Figure 34. Type 10, Class 1, Coated, Nylon 6
Original and After Treatment

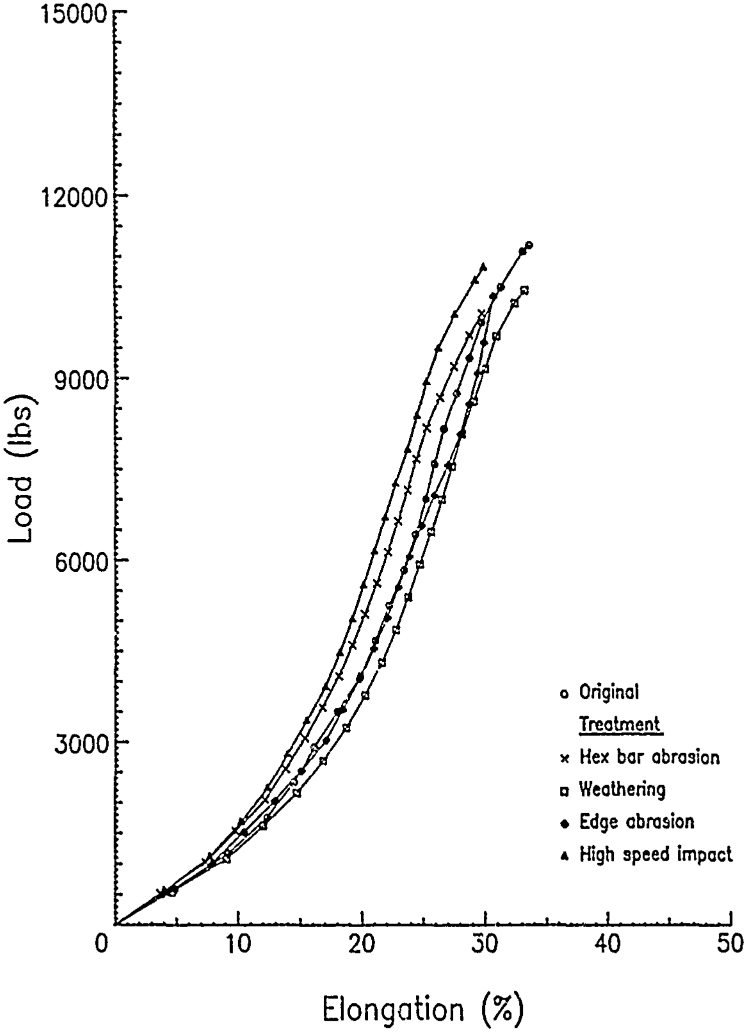

Figure 35. Type 10, Class 2, Coated, Nylon 6
Original and After Treatment

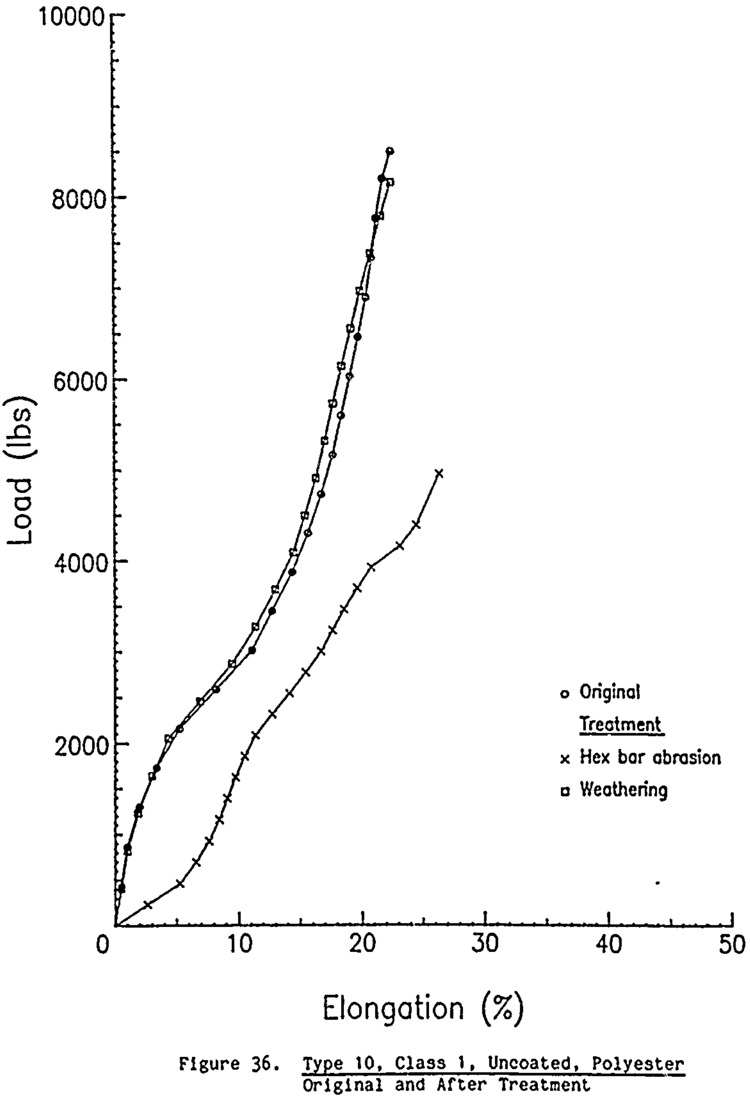

Figure 36. Type 10, Class 1, Uncoated, Polyester Original and After Treatment

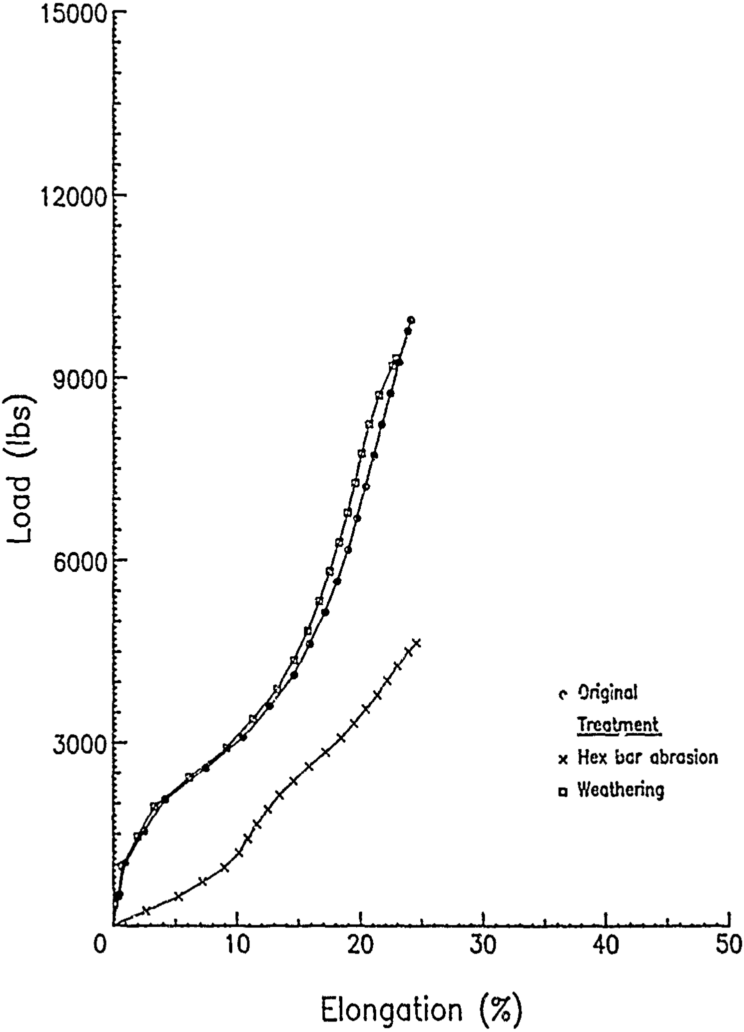

Figure 37. Type 10, Class 2, Uncoated, Polyester Original and After Treatment

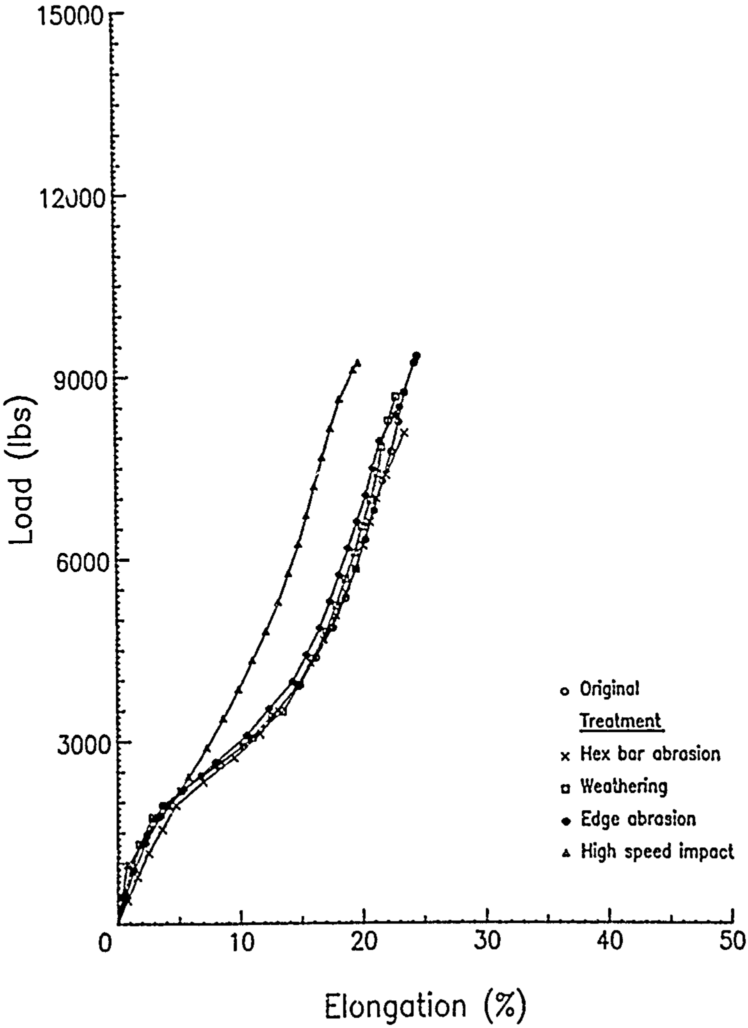

Figure 38. Type 10, Class 1, Coated, Polyester Original and After Treatment

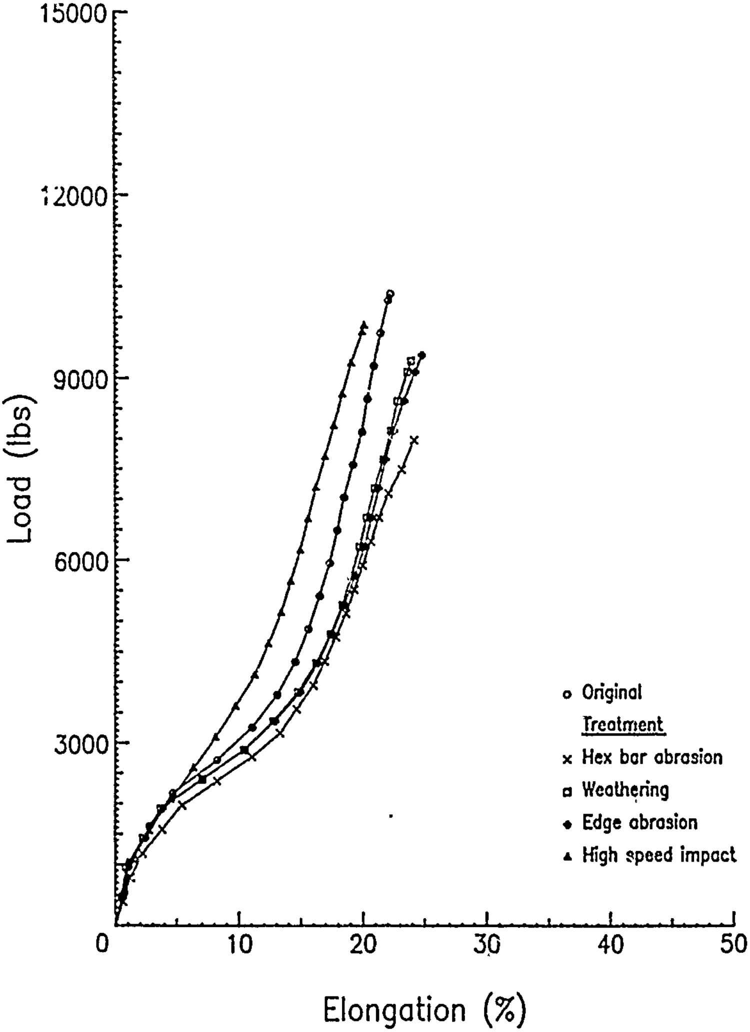

Figure 39. Type 10, Class 2, Coated, Polyester
Original and After Treatment

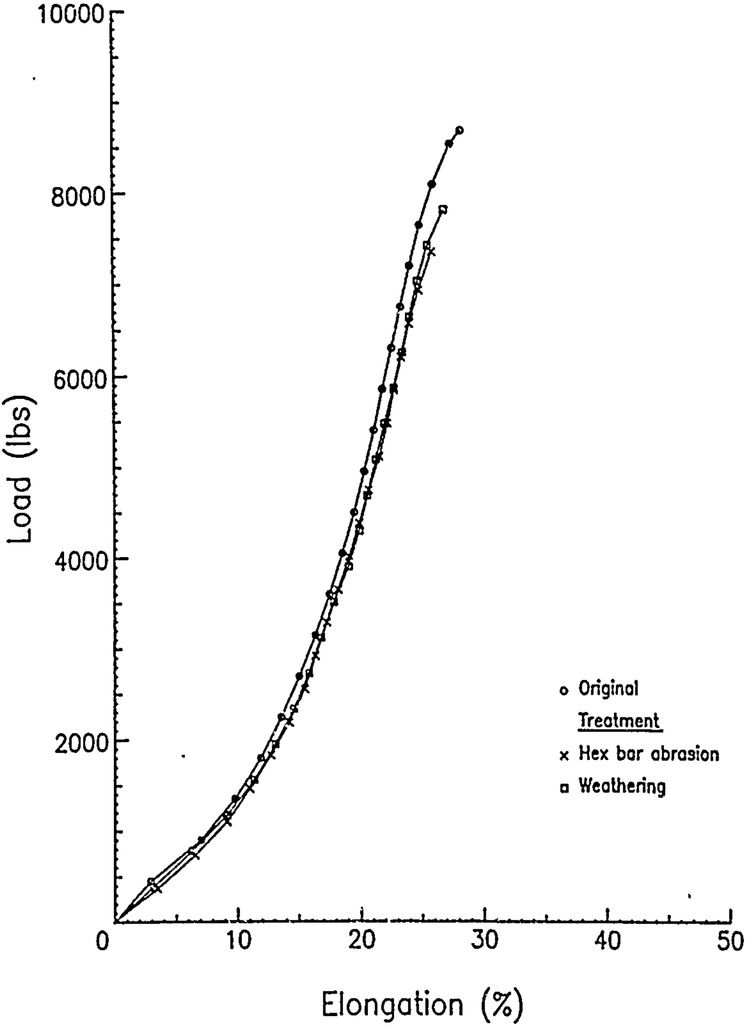

Figure 40. Type 13, Class 1, Uncoated, Nylon 6,6
Original and After Treatment

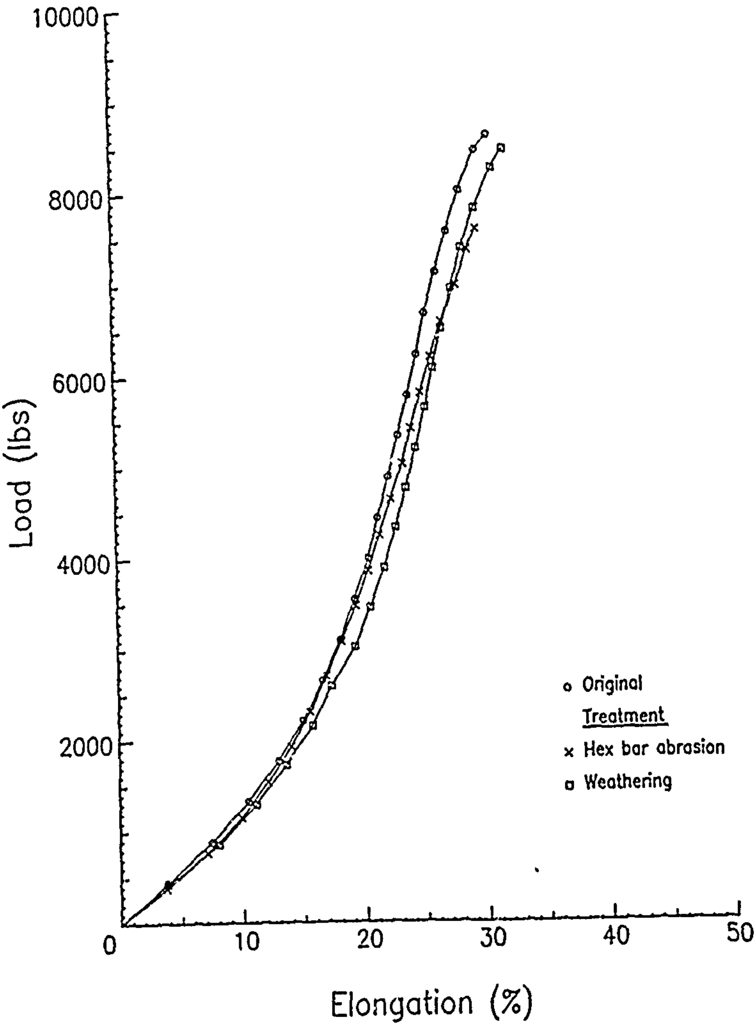

Figure 41. Type 13, Class 2, Uncoated, Nylon 6,6
Original and After Treatment

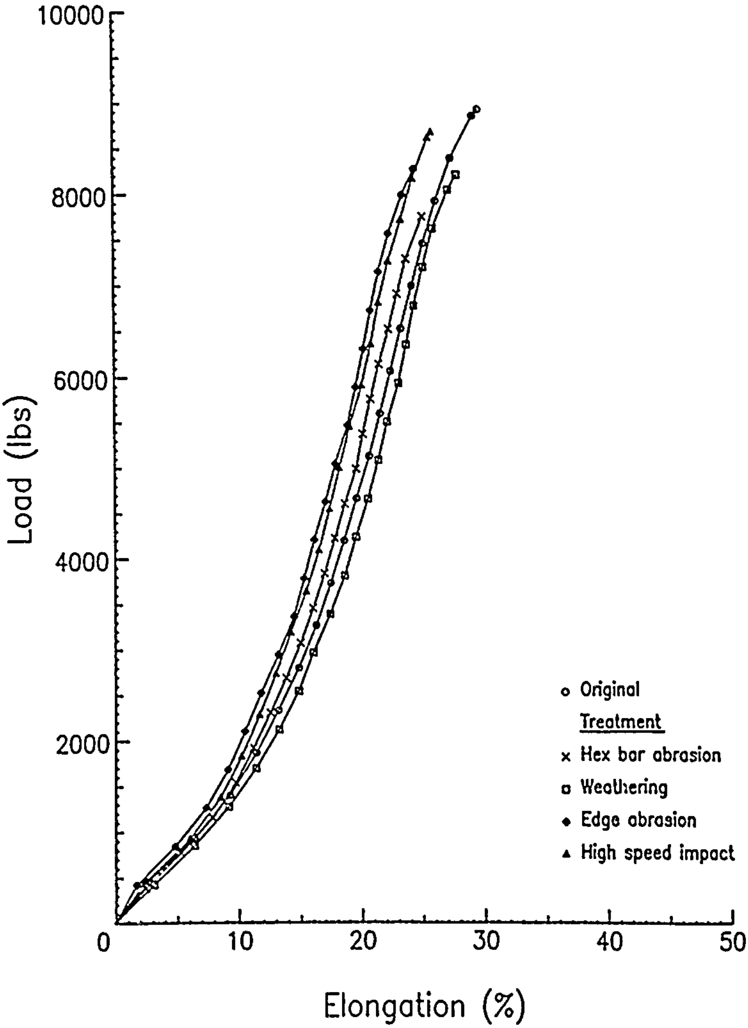

Figure 42. Type 13, Class 1, Coated, Nylon 6,6
Original and After Treatment

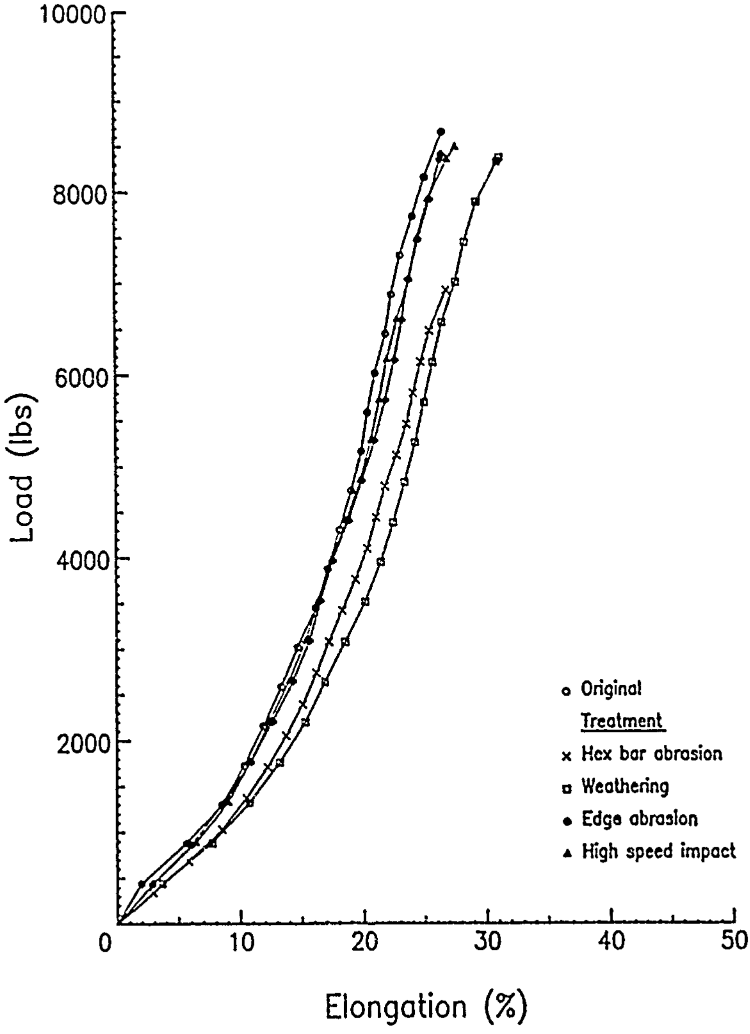

Figure 43. Type 13, Class 2, Coated, Nylon 6.6
Original and After Treatment

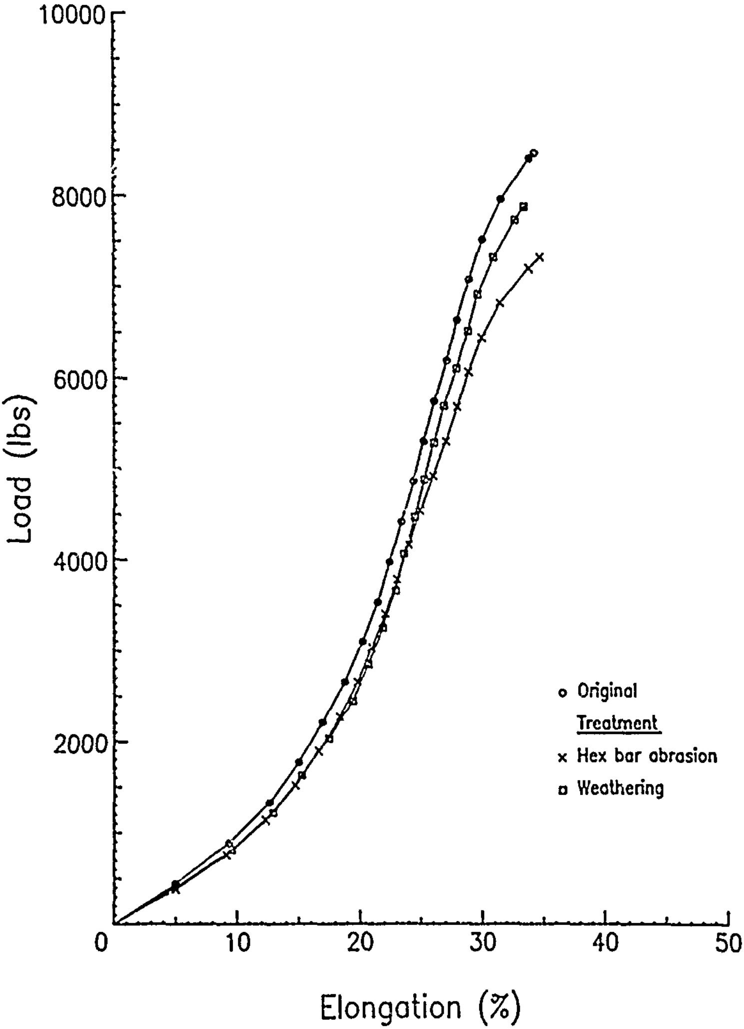

Figure 44. Type 13, Class 1, Uncoated, Nylon 6
Original and After Treatment

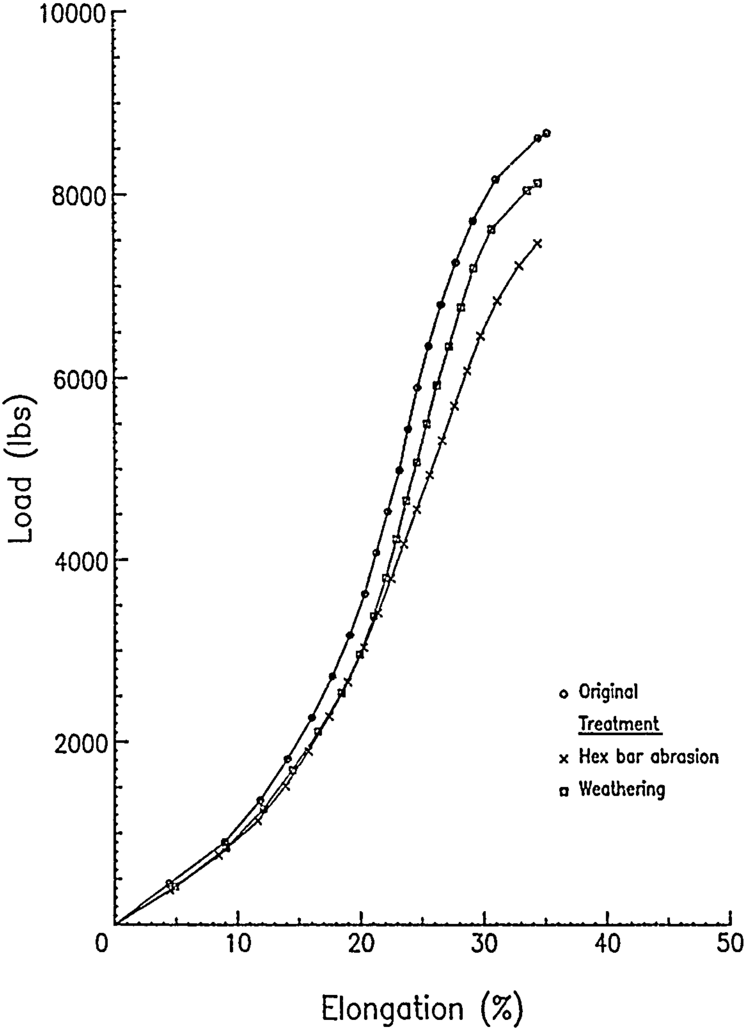

Figure 45. Type 13, Class 2, Uncoated, Nylon 6
Original and After Treatment

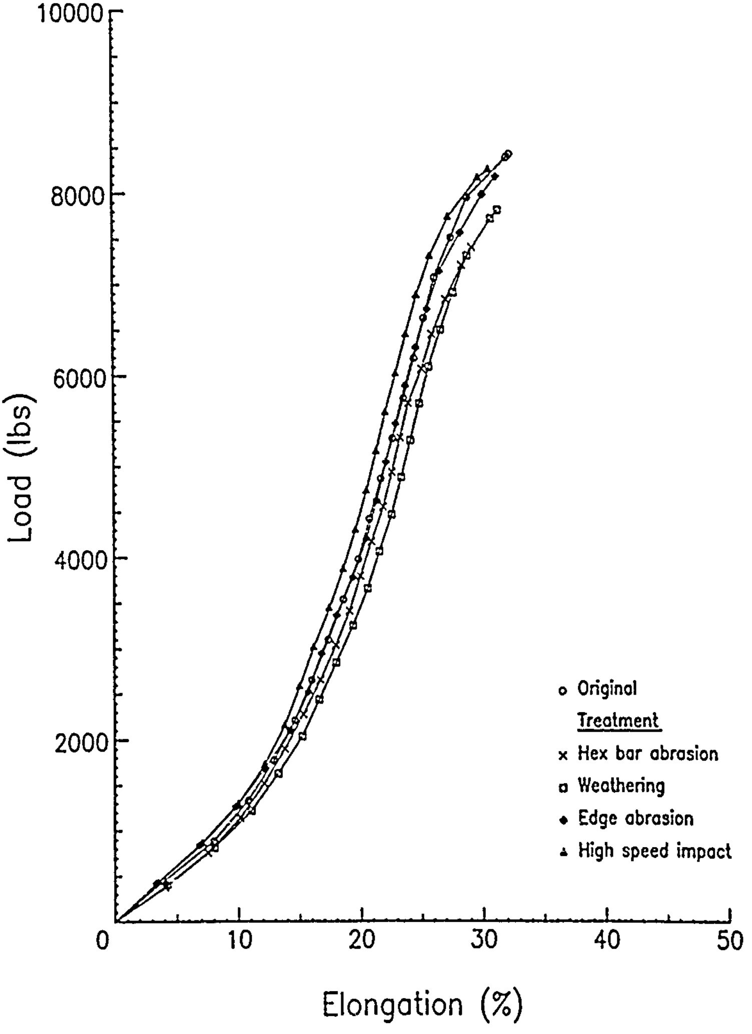

Figure 46. Type 13, Class 1, Coated, Nylon 6
Original and After Treatment

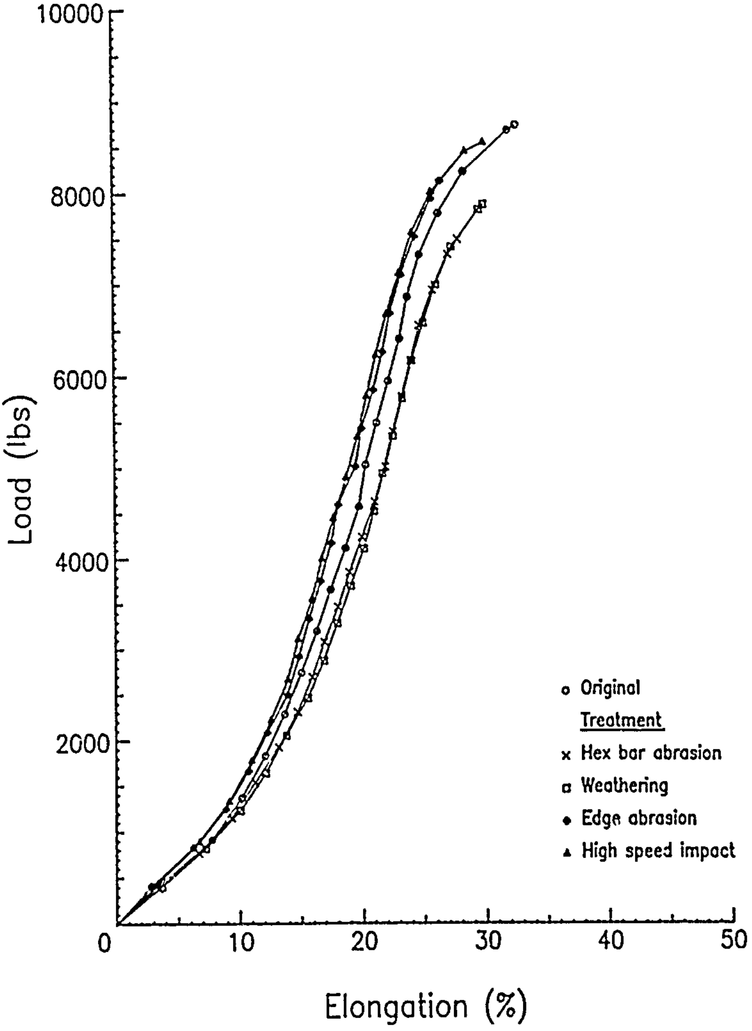

Figure 47. Type 13, Class 2, Coated, Nylon 6 Original and After Treatment

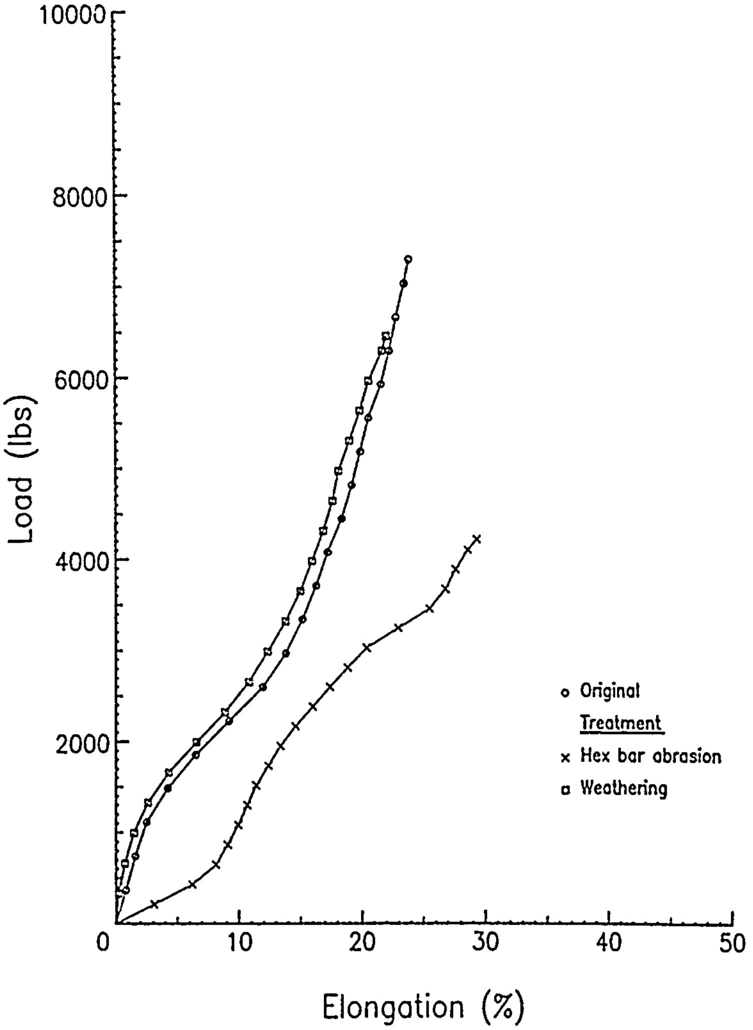

Figure 48. Type 13, Class 1, Uncoated, Polyester
Original and After Treatment

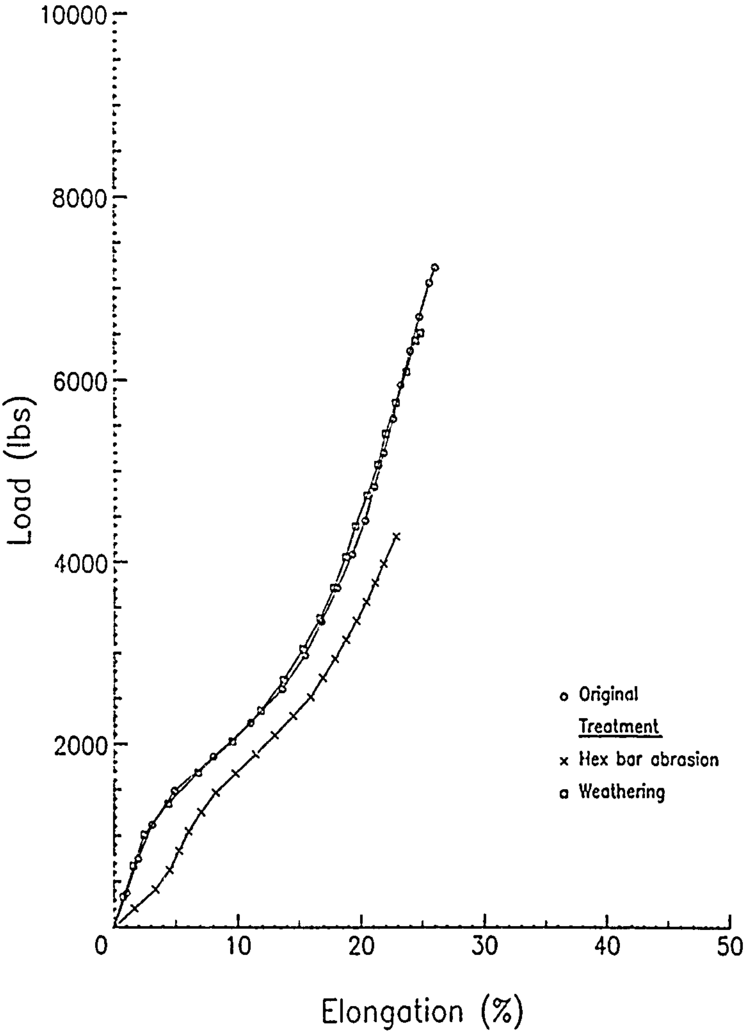

Figure 49. Type 13, Class 2, Uncoated, Polyester
Original and After Treatment

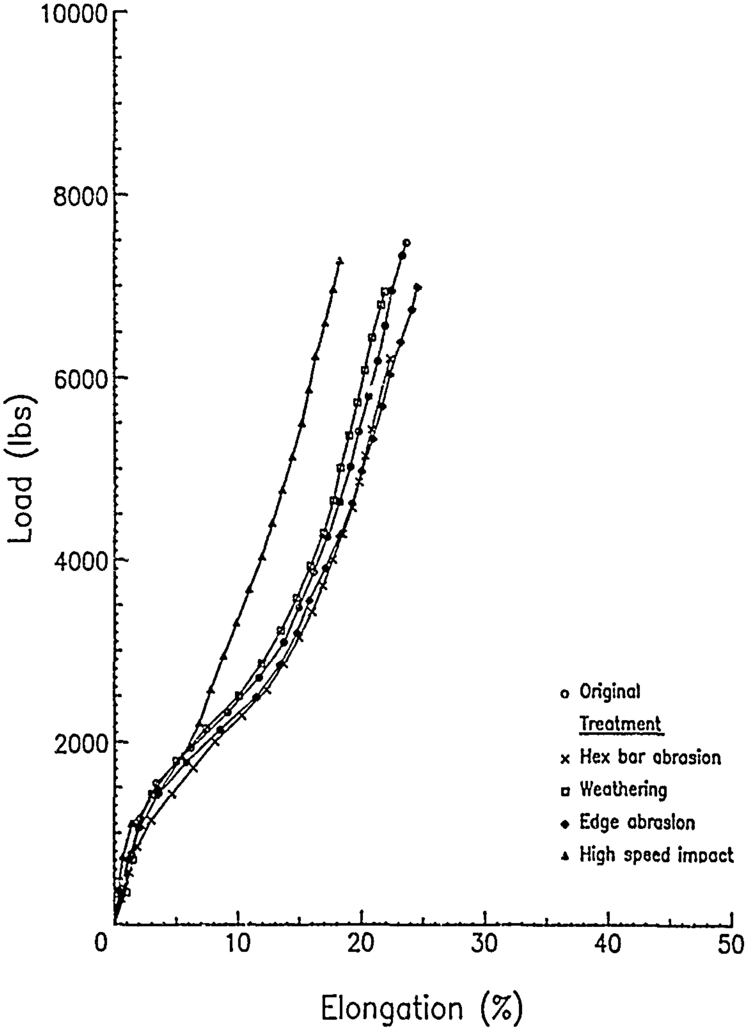

Figure 50. Type 13, Class 1, Coated, Polyester
Original and After Treatment

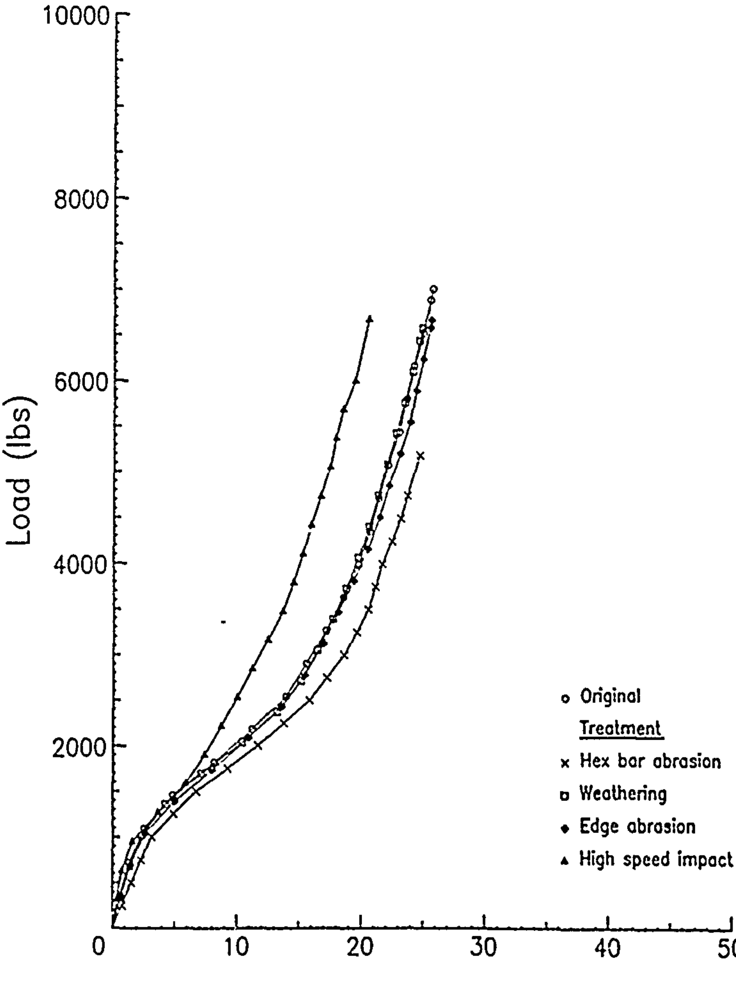

Figure 51. Type 13, Class 2, Coated, Polyester
Original and After Treatment

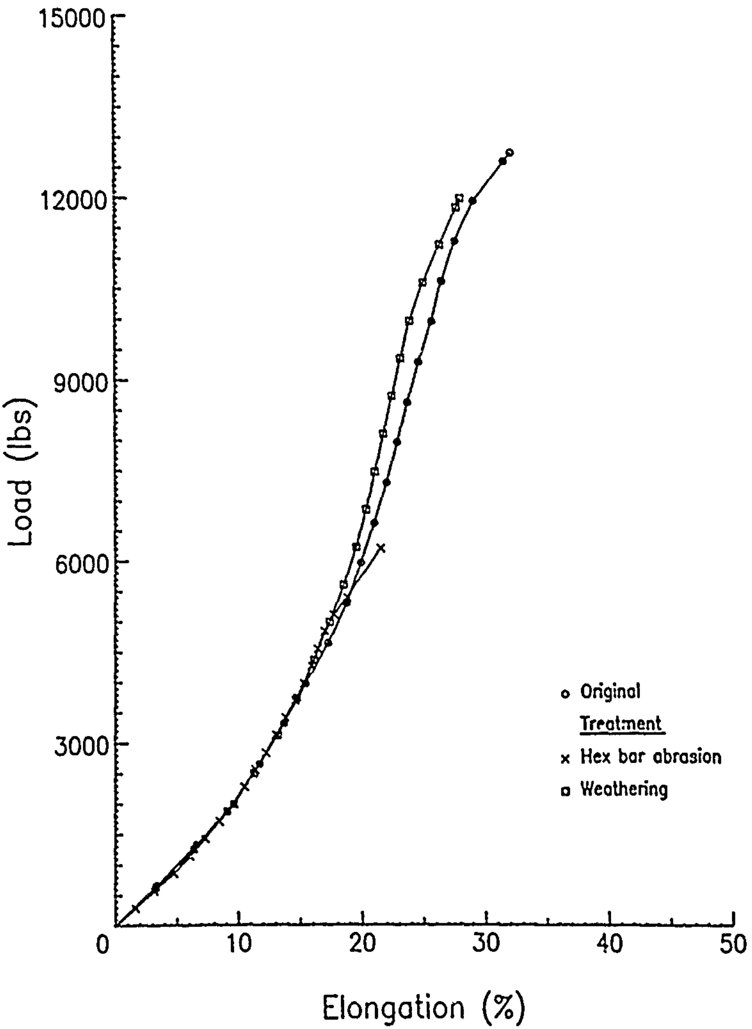

Figure 52. Type 19, Class 1, Uncoated, Nylon 6,6
Original and After Treatment

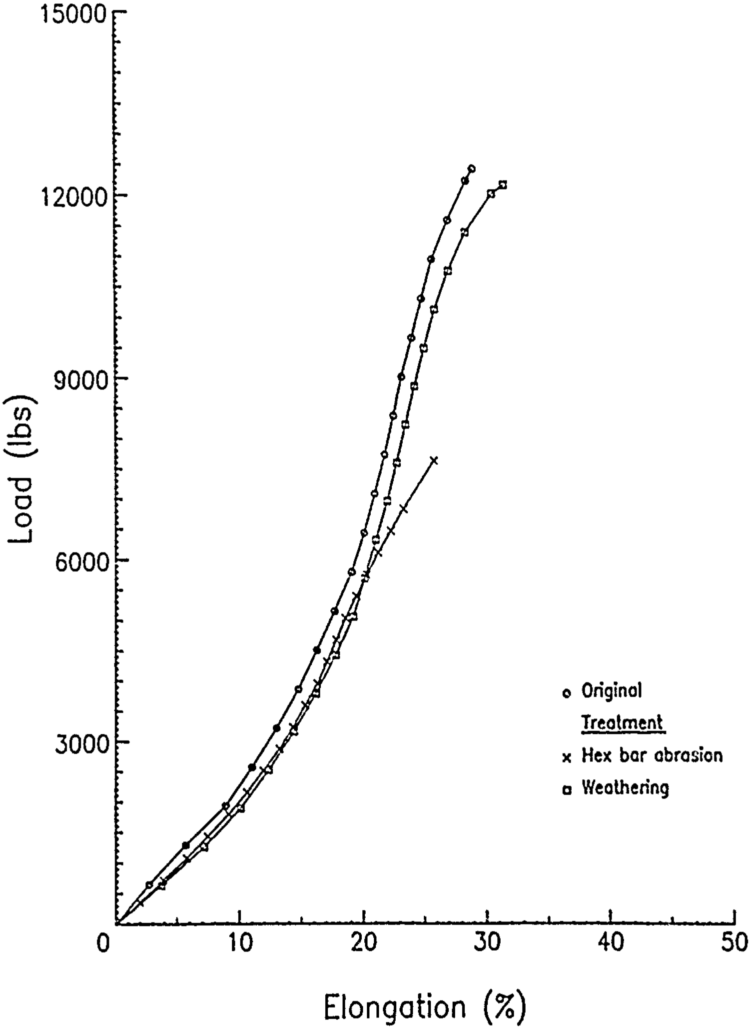

Figure 53. Type 19, Class 2, Uncoated, Nylon 6,6 Original and After Treatment

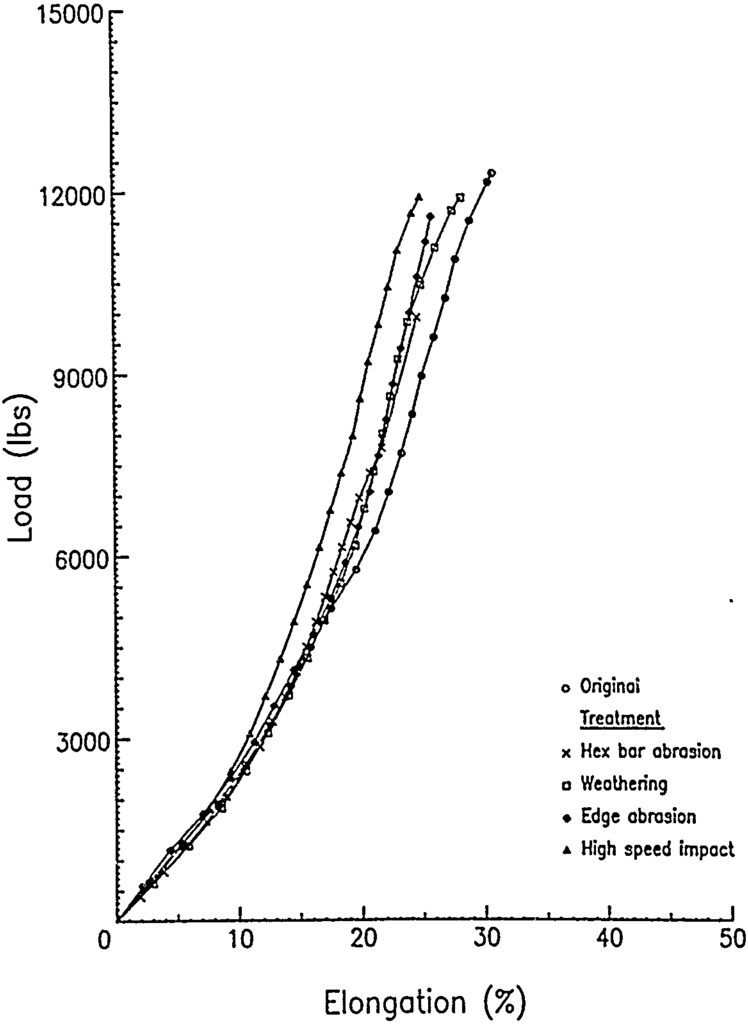

Figure 54. Type 19, Class 1, Coated, Nylon 6,6
Original and After Treatment

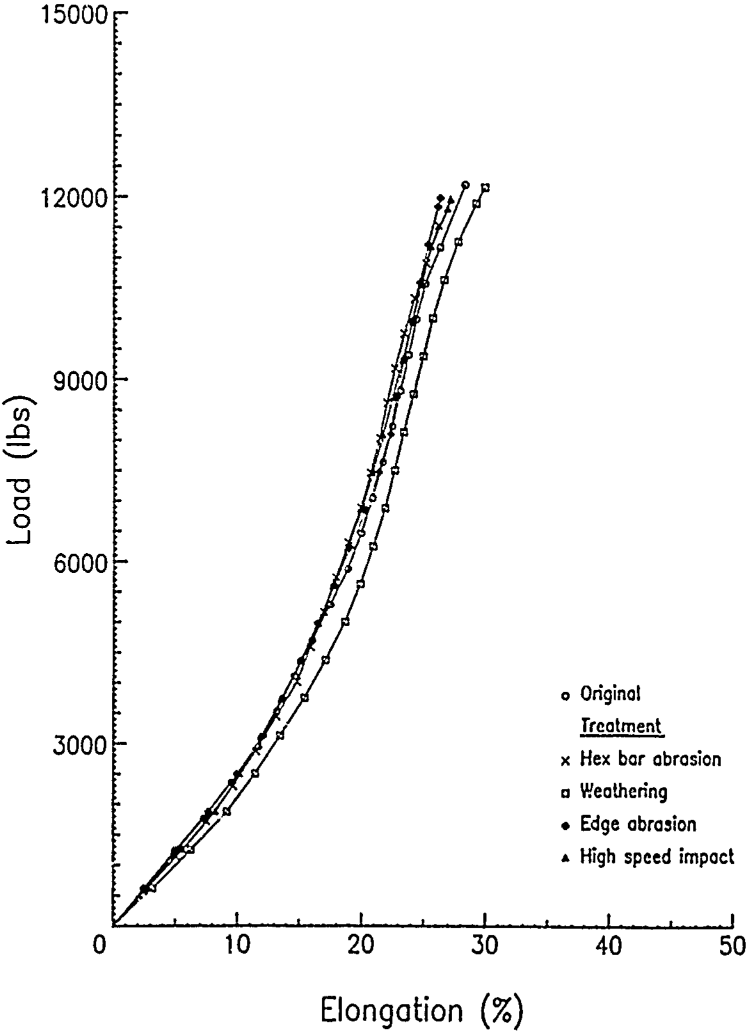

Figure 55. Type 19, Class 2, Coated, Nylon 6,6
Original and After Treatment

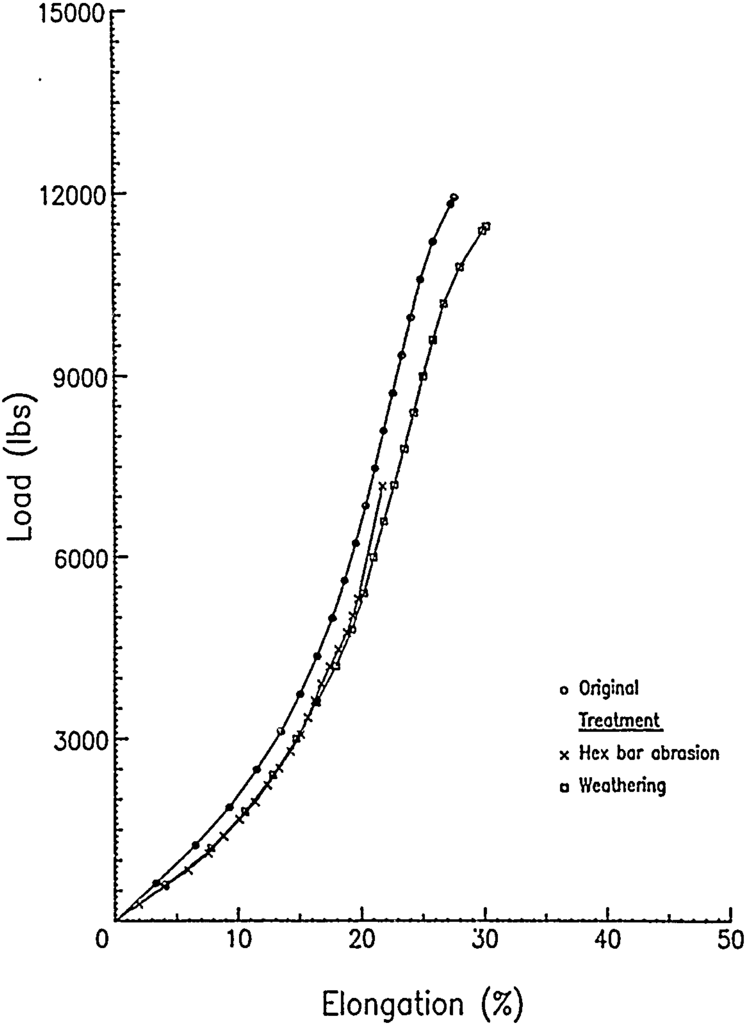

Figure 56. Type 19, Class 1, Uncoated, Nylon 6
Original and After Treatment

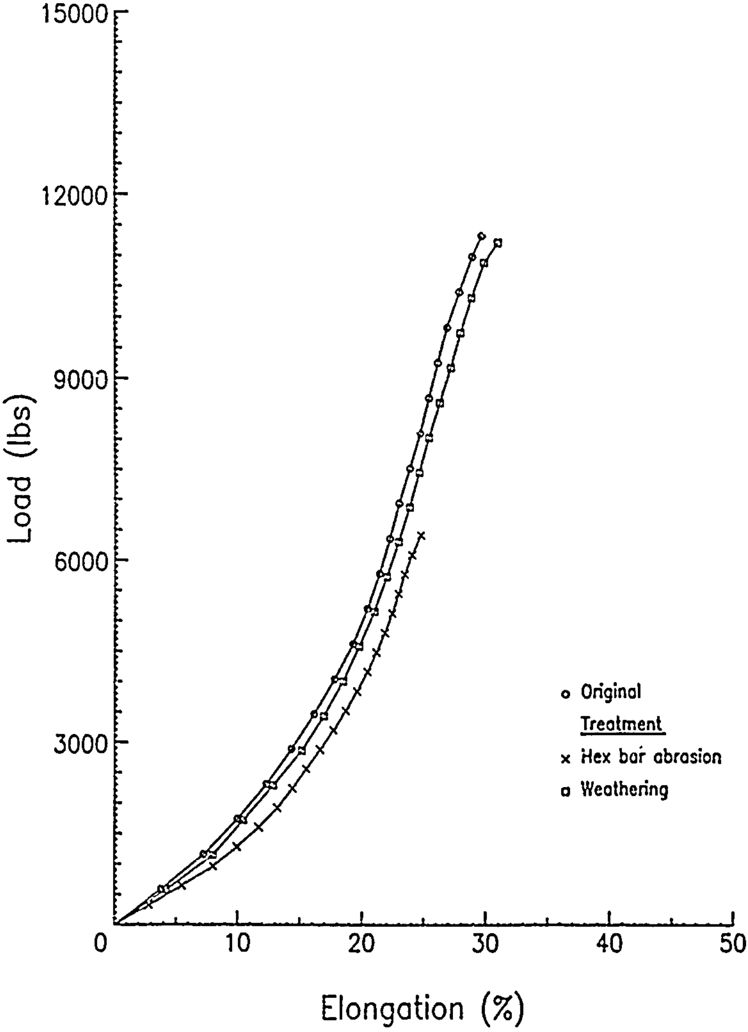

Figure 57. Type 19, Class 2, Uncoated, Nylon 6
Original and After Treatment

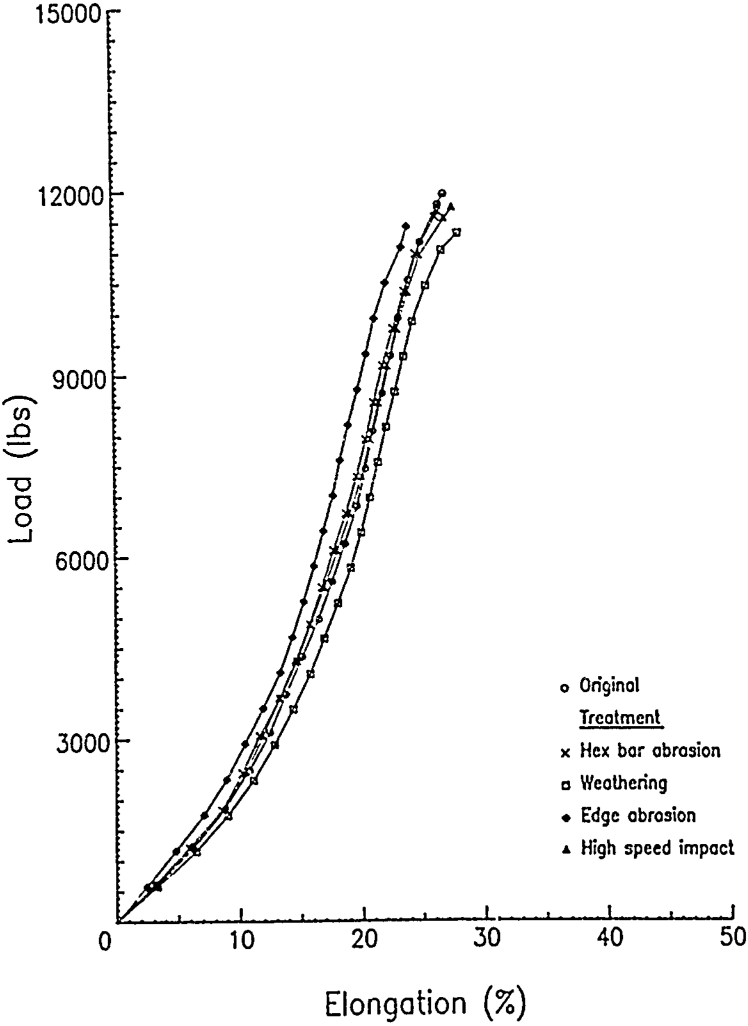

Figure 58. Type 19, Class 1, Coated, Nylon 6
Original and After Treatment

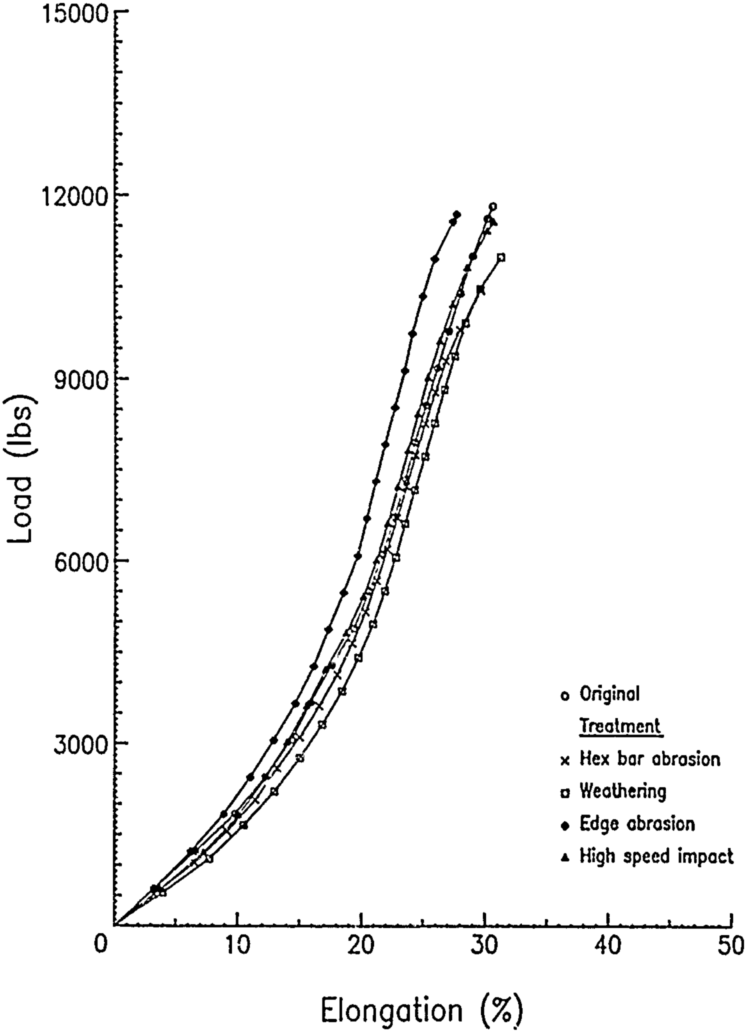

Figure 59. Type 19, Class 2, Coated, Nylon 6
Original and After Treatment

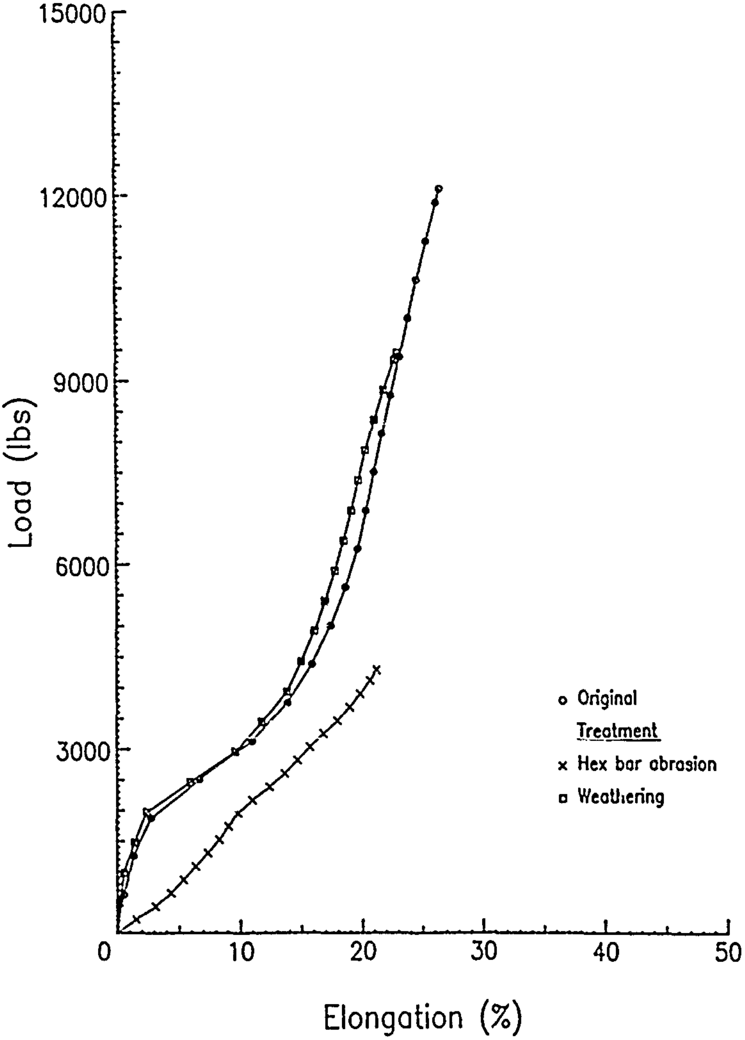

Figure 60. Type 19, Class 1, Uncoated, Polyester Original and After Treatment

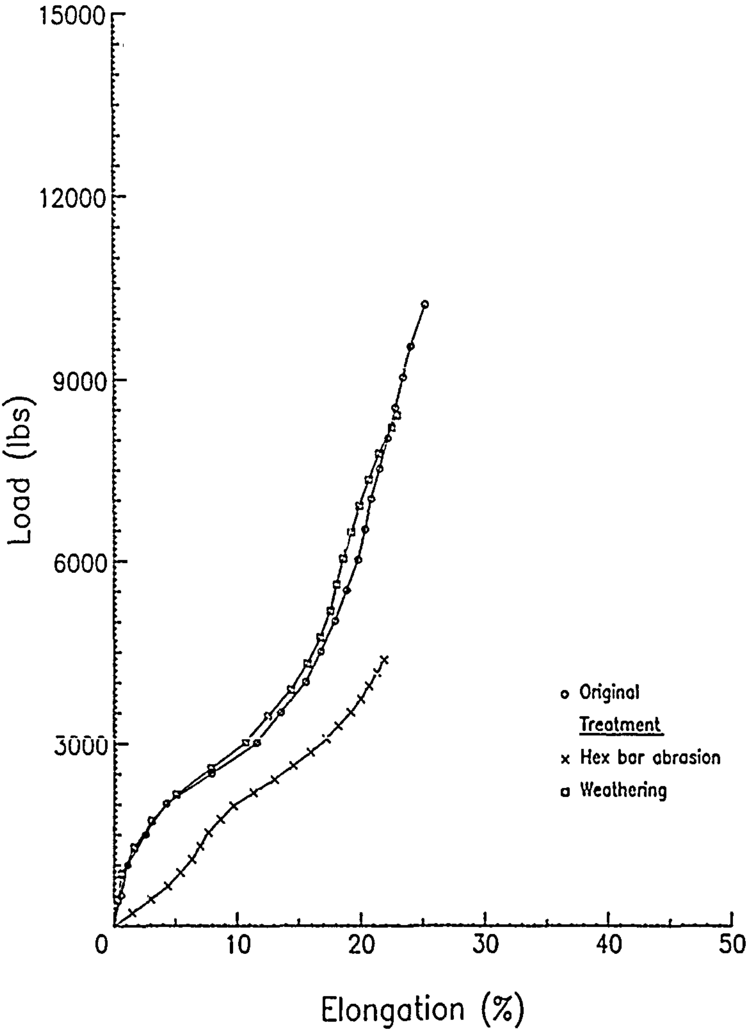

Figure 61. Type 19, Class 2, Uncoated, Polyester Original and After Treatment

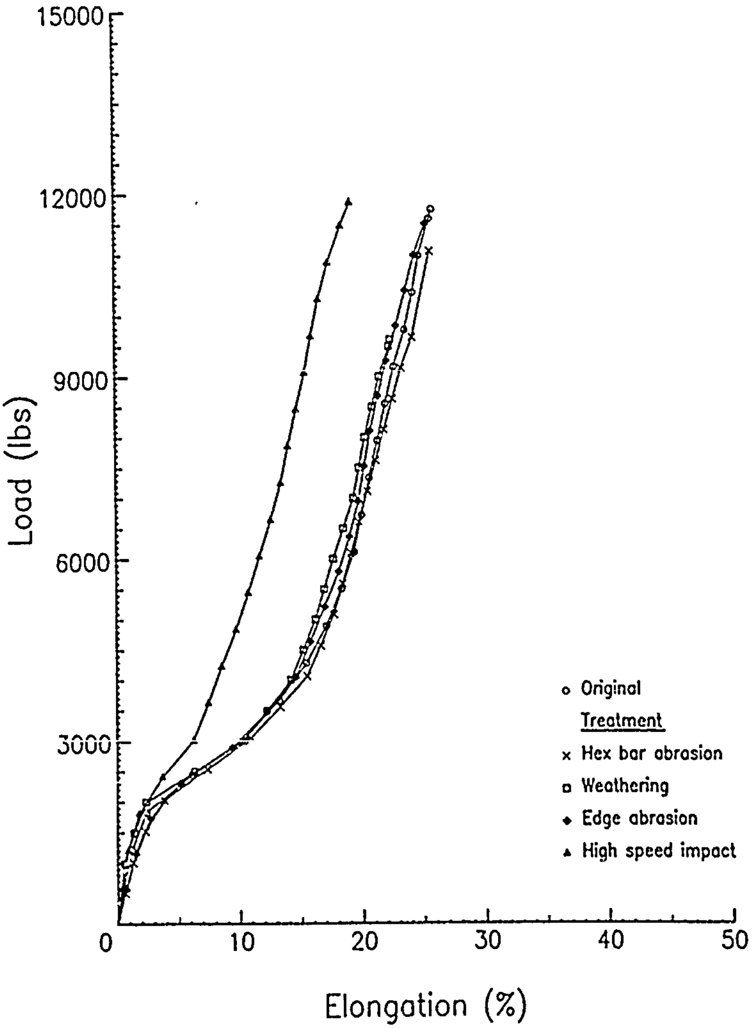

Figure 62. Type 19, Class 1, Coated, Polyester Original and After Treatment

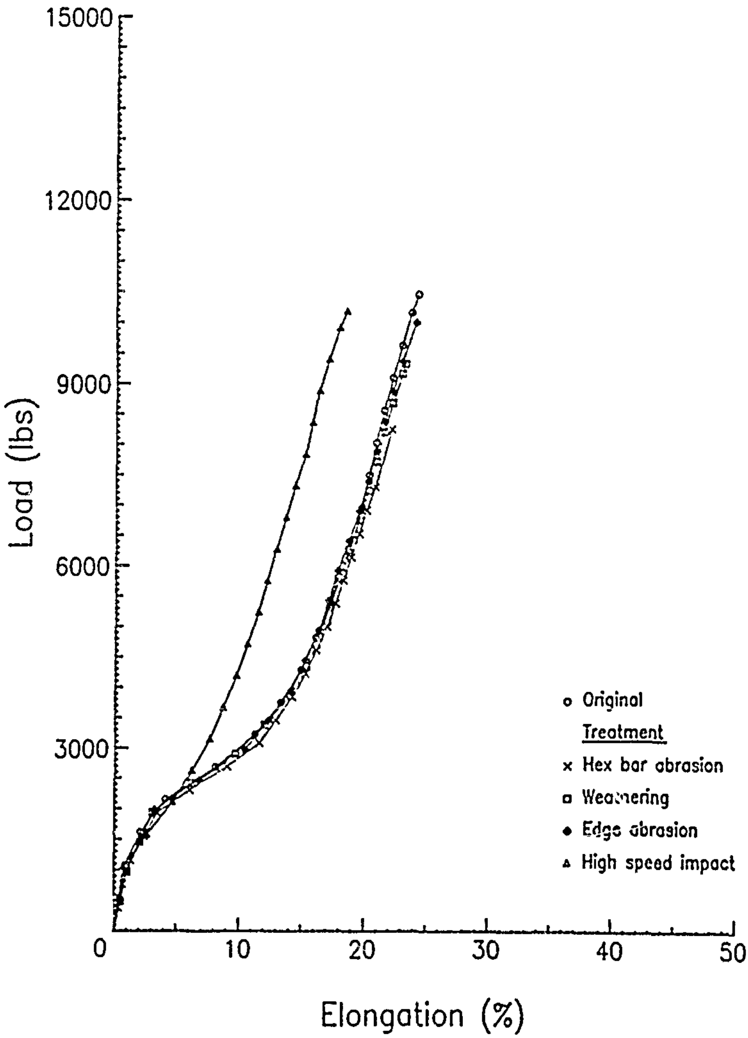

Figure 63. Type 19, Class 2, Coated, Polyester Original and After Treatment

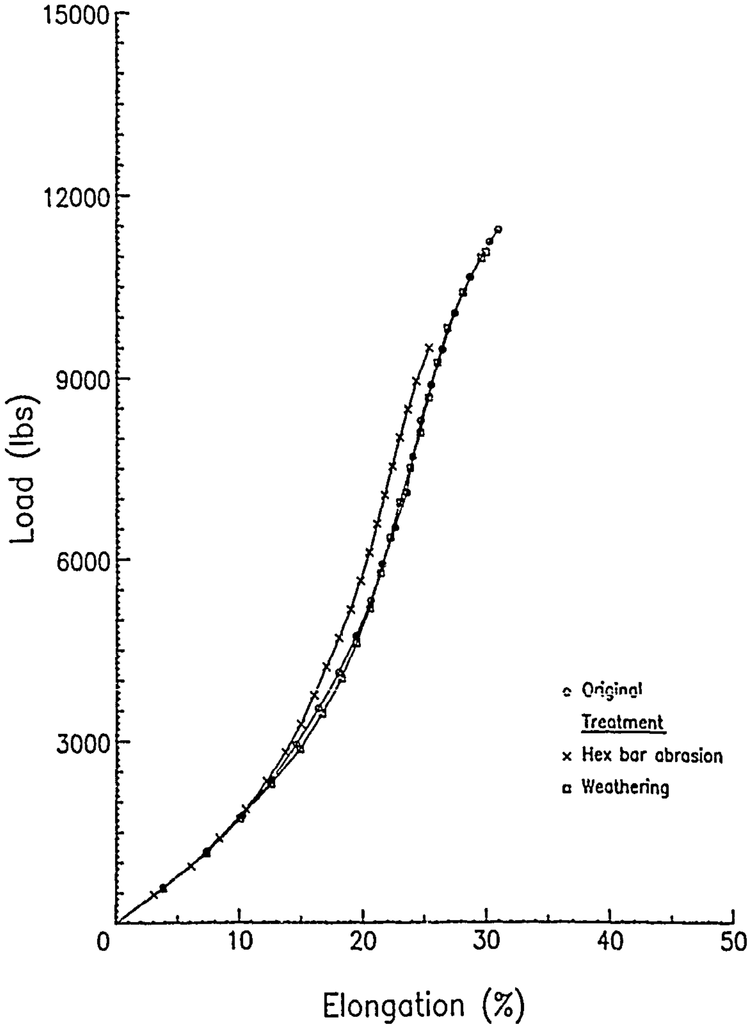

Figure 64. Type 22, Class 1, Uncoated, Nylon 6,6
Original and After Treatment

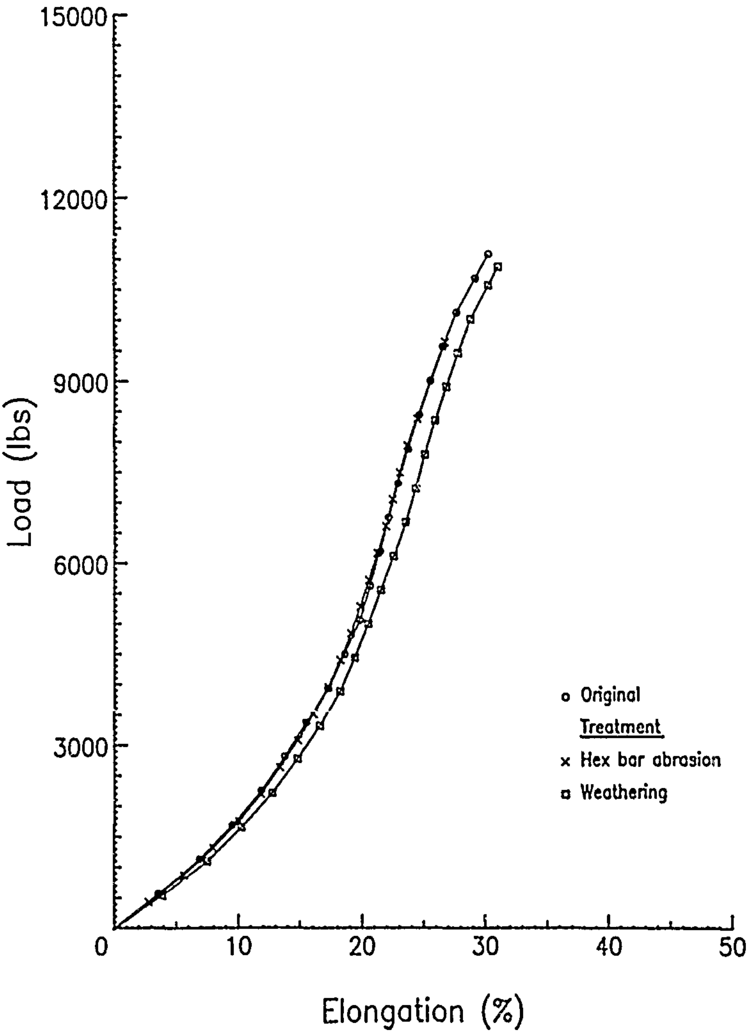

Figure 65. Type 22, Class 2, Uncoated, Nylon 6,6
Original and After Treatment

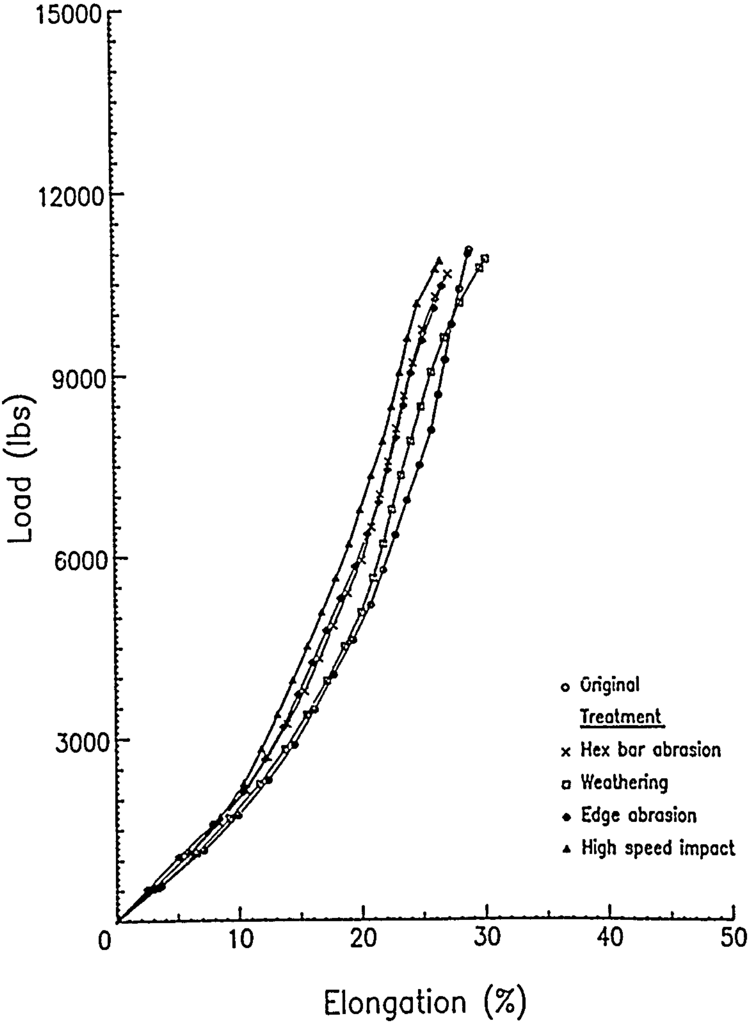

Figure 66. Type 22, Class 1, Coated, Nylon 6,6
Original and After Treatment

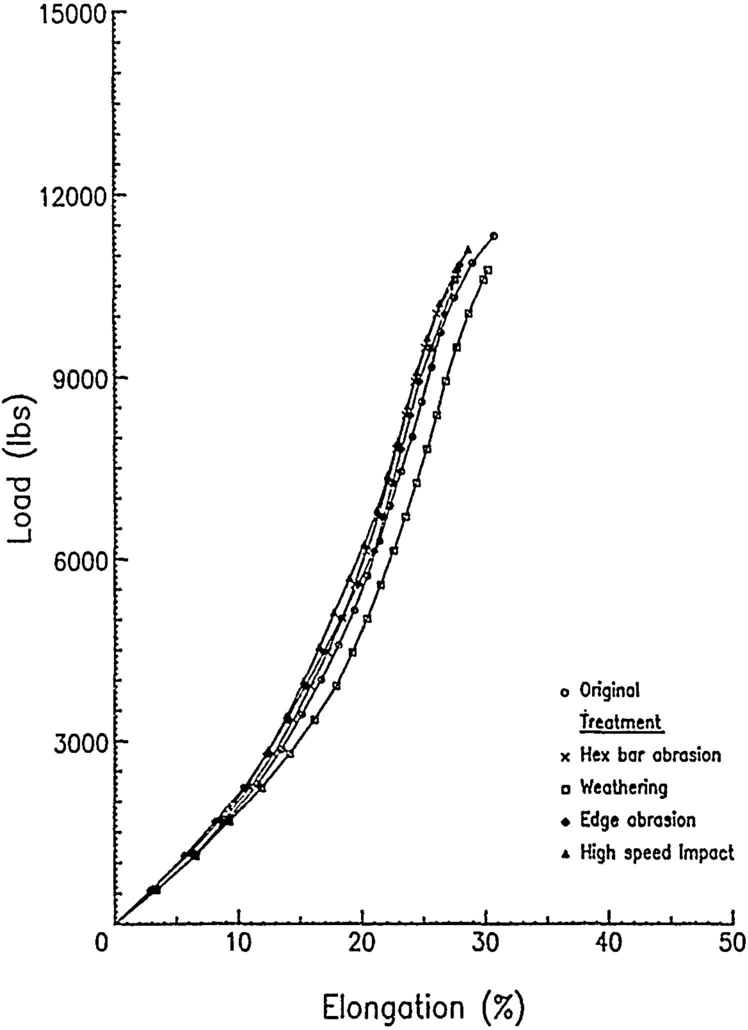

Figure 67. Type 22, Class 2, Coated, Nylon 6,6
Original and After Treatment

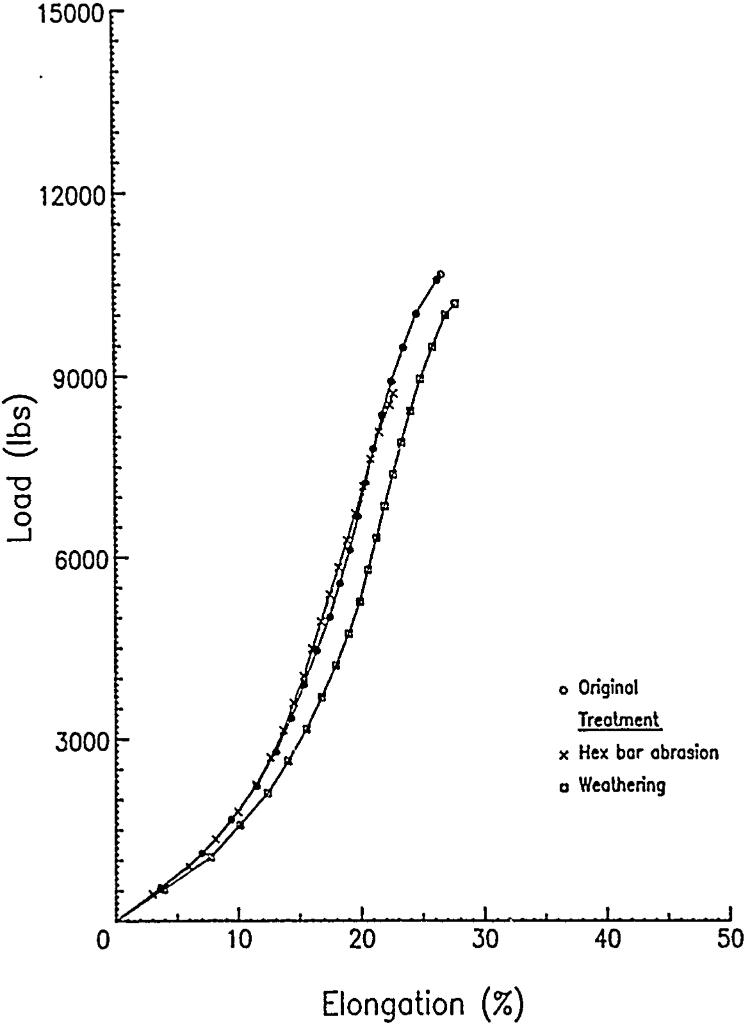

Figure 68. Type 22, Class 1, Uncoated, Nylon 6
Original and After Treatment

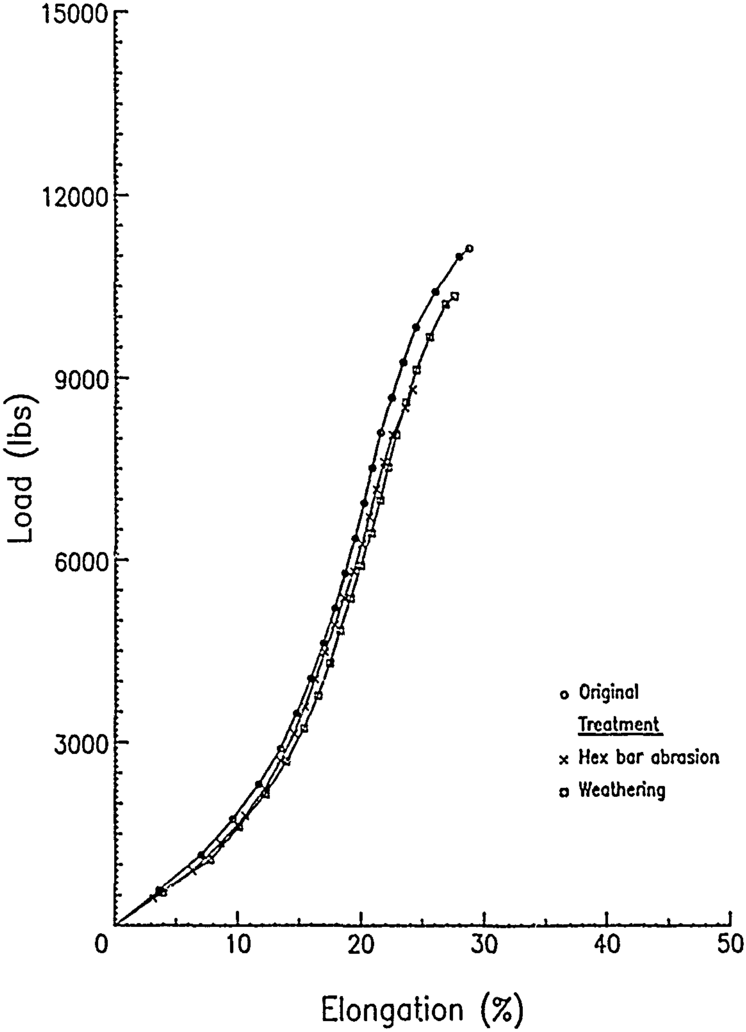

Figure 69. Type 22, Class 2, Uncoated, Nylon 6
Original and After Treatment

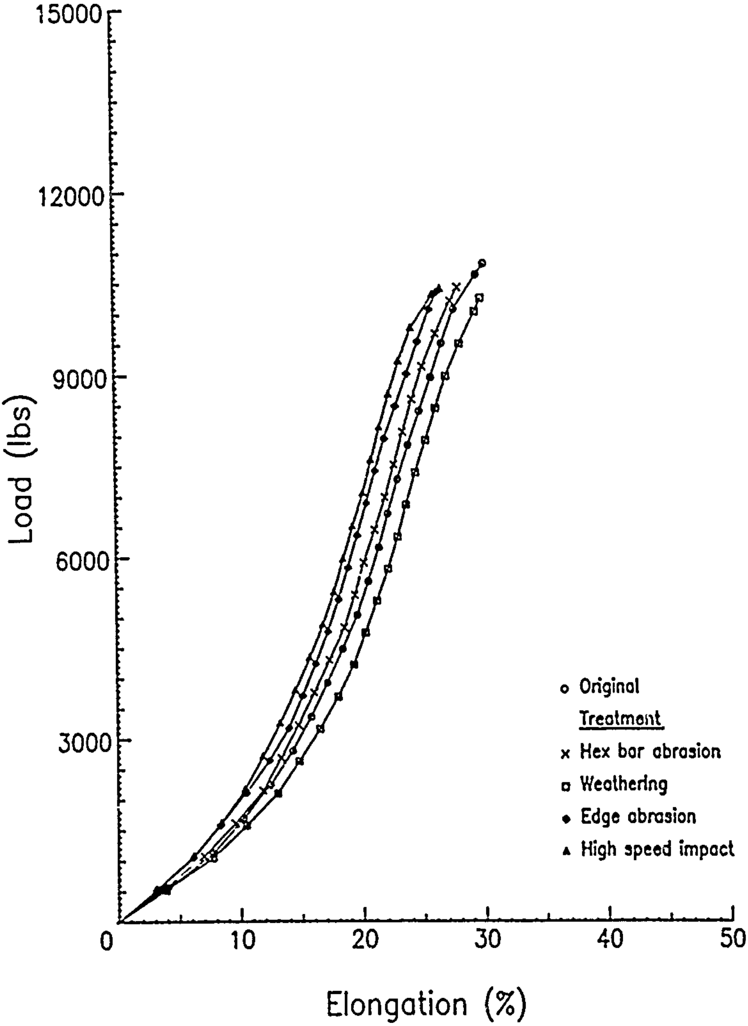

Figure 70. Type 22, Class 1, Coated, Nylon 6 Original and After Treatment

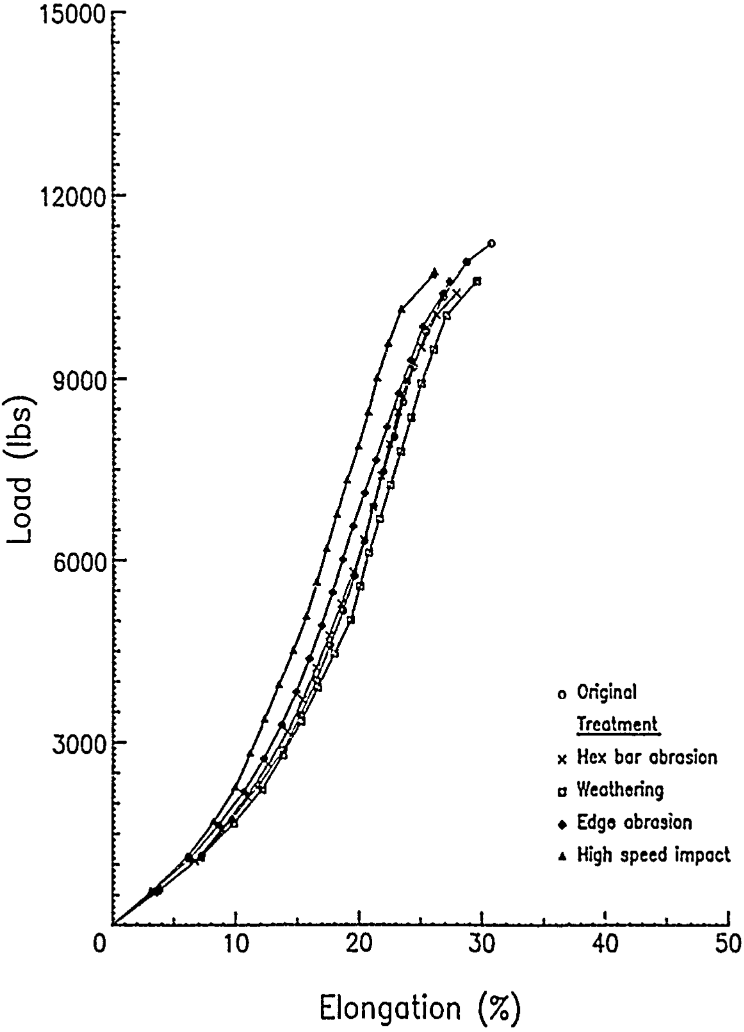

Figure 71. Type 22, Class 2, Coated, Nylon 6
Original and After Treatment

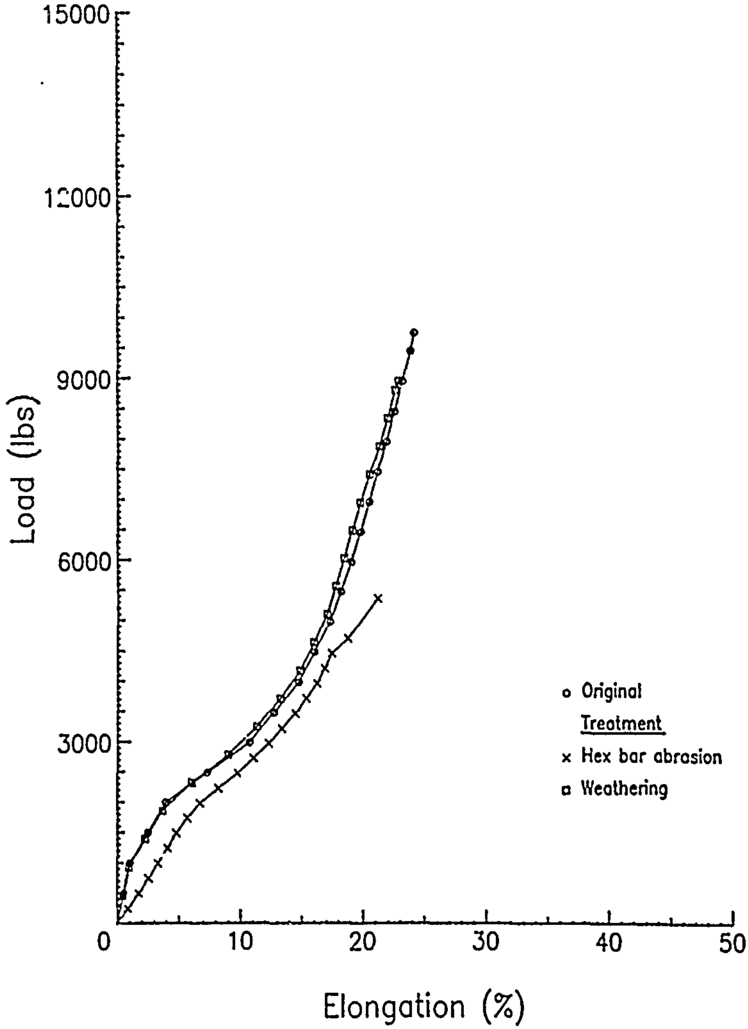

Figure 72. Type 22, Class 1, Uncoated, Polyester Original and After Treatment

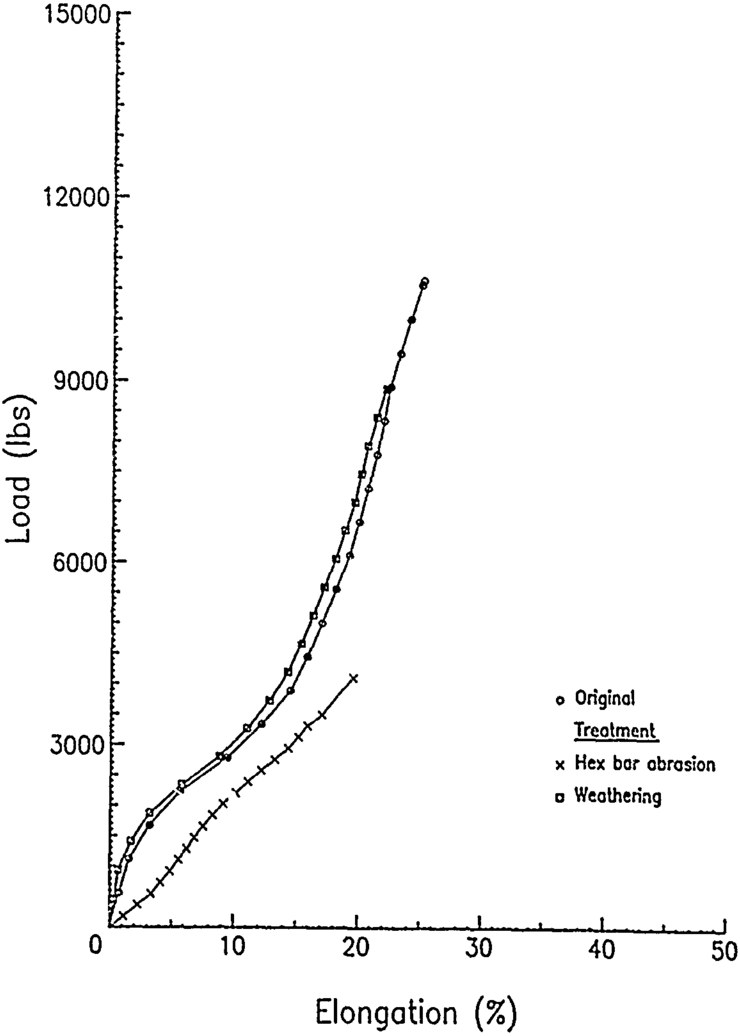

Figure 73. Type 22, Class 2, Uncoated, Polyester Original and After Treatment

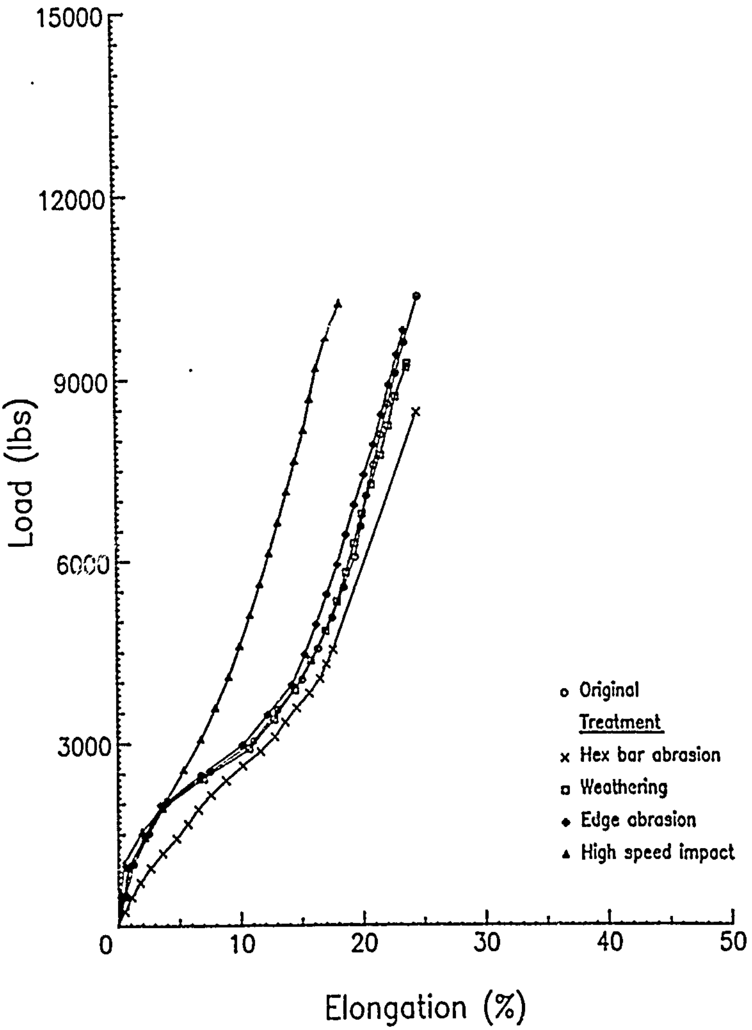

Figure 74. Type 22, Class 1, Coated, Polyester Original and After Treatment

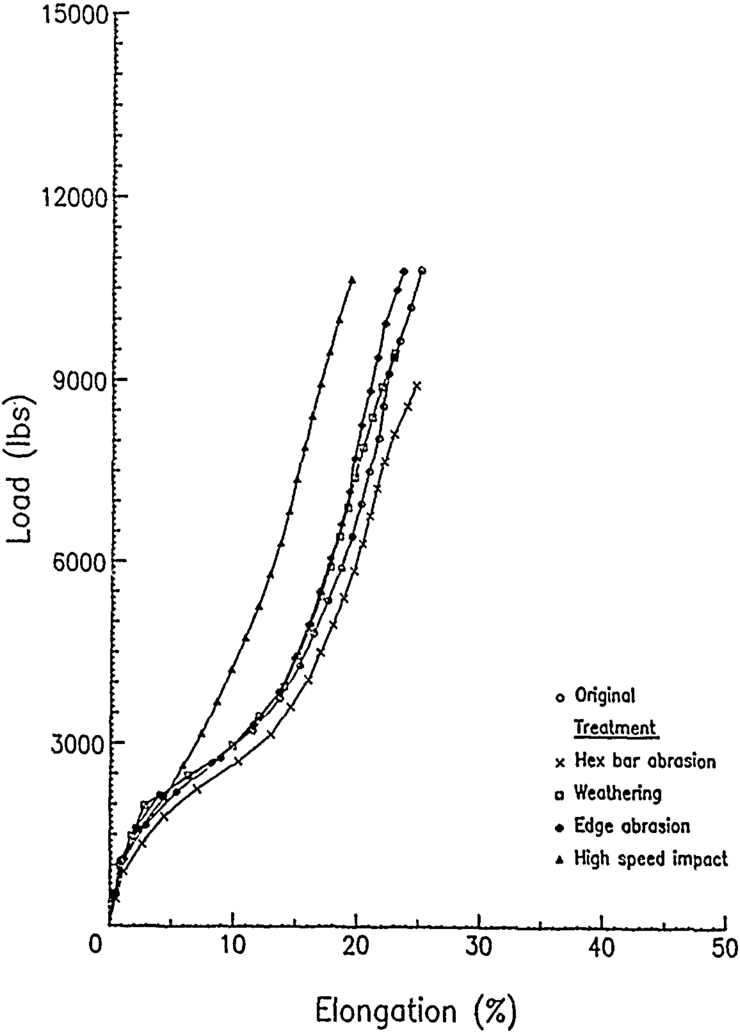

Figure 75. Type 22, Class 2, Coated, Polyester Original and After Treatment

Results for energy absorption at break are given in Table 9. There is again no spec for these values. The energy value is computed as the area under the load-elongation curve up to the breaking point, and is presumably the amount of energy which a webbing can absorb at failure. As these values are a product of strength and elongation, the results are similar to those noted above: no significant differences between shuttle and shuttleless constructions, no significant difference between nylon 6,6 and nylon 6, and somewhat reduced values of energy absorption for the polyester constructions. Most of the polyester energy absorption values fall within 65 and 85% of the comparable nylon 6,6 shuttle values. The same provisions apply to interpretation of these results - they cannot be clearly attributed to fiber type because of construction variations, and the implications of energy absorption data in relation to actual use are not clearly known.

6. Accelerated Weathering

All three of the fiber types studied are well known to exhibit some degradation in properties after exposure to sunlight [11]. For nylon, the degradation can occur by direct disruption of C-N bonds, or by abstraction of hydrogen atoms from the carbon adjacent to the NH group. For polyester, degradation can occur by absorption at the ester carbonyl. The performance of both nylon and polyester is influenced by many factors such as the presence of stabilizers, dyes, yarn denier or fabric construction. Accelerated weathering, as an attempt to simulate actual outdoor exposure of these webbings, is subject to much variability and has historically been difficult to interpret with great accuracy. For this reason, as described in the Test Methods section, we have chosen to weather matched pairs of shuttle and shuttleless constructions for the best comparison of constructional effects.

Values for tensile strength, elongation and energy absorption after accelerated weathering are shown in Tables 10, 11 and 12. There is a specification of 95% of original strength for all resin coated samples, and no specification for uncoated webbings. Many values within the nylon 6,6 and nylon 6 groups are slightly below spec, with averages of the coated values ranging from 91 to 94%. The behavior of the nylon 6,6 and nylon 6 to the accelerated weathering exposure is statistically equivalent. No nylon webbings show less than 85% strength retention, and on an absolute, rather than normalized basis, all show tensile strengths greater than the minimum original spec. A large part of this departure from spec may be attributed to the particularly variable nature of weathering, and also to the fact that weathering was conducted with a Xenon bulb Weatherometer as an approved replacement for the carbon arc. The Xenon bulb spectrum, as discussed in Test Methods, better corresponds to the exposure to sunlight, which is assumed to be the degradative agent in accelerated weathering.

The coated polyester webbings show average values for strength retention of 88 and 89% for the shuttle and shuttleless constructions, but these values are statistically equivalent to the nylon values. Several individual coated polyester constructions did show values below 85% (Type XIX shuttleless resin coated had the lowest value at 81.8%) but because of the lack of optimum construction, this cannot clearly be attributed to a characteristic of the polyester, but may be a function of the construction. The construction might, for example, provide more severe exposure of the warp yarns, or shrinkage imbalance during the wet cycle.

TABLE 10. Tensile Strength (lb) After Accelerated Weathering (average of 5 values)

			Nylon 6,6				Nylon 6				Polyester			
			SH		SL		SH		SL		SH		SL	
Webbing Type	Treatment	Spec (% of Original)	lb	% of Orig	lb	% of Orig	lb	% of Orig	lb	% of Orig	lb	% of Orig	lb	% of Orig
VI	none		3160	91.7	3039	89.0	3057	90.8	3094	88.8	2508	83.4	2192	85.2
	resin	95	3025	86.2	2901	85.7	3043	89.4	3045	88.5	2482	82.7	2209	89.8
VIII	none		4616	90.2	4662	89.1	4497	91.2	4567	92.9	3749	81.2	3717	81.5
	resin	95	4624	91.0	4737	92.8	4412	90.5	4478	88.5	3920	86.7	3995	85.0
X	none		10475	93.4	10485	99.6	10223	94.9	10656	95.7	8160	96.1	9320	93.5
	resin	95	10150	90.2	10285	93.3	10370	93.0	10460	93.3	8690	92.8	9280	89.4
XIII	none		7813	89.9	8457	98.2	7872	93.0	8123	93.6	6460	88.5	6534	90.2
	resin	95	8224	91.9	8410	96.6	7830	92.7	7879	90.0	6940	92.8	6590	93.9
XIX	none		11964	94.0	12183	97.9	11450	96.0	11230	99.0	9463*	78.1	8400	82.2
	resin	95	11914	96.7	12161	99.7	11330	94.7	11012	92.9	9610	81.8	9360	89.2
XXII	none		11081	96.8	10912	98.3	10180	95.4	10353	92.9	8950	91.9	8900	83.4
	resin	95	10907	98.8	10771	95.1	10274	94.9	10608	94.5	9256	89.4	9460	87.5
	Average of all values			92.6%		94.6%		93.0%		92.6%		87.1%		87.6%
	Standard deviation			3.6		4.7		2.2		3.2		5.7		4.1
	Average of uncoated			92.7%		95.4%		93.6%		93.8%		86.6%		86.0%
	Standard deviation			2.6		4.9		2.2		3.4		6.8		4.8
	Average of resin coated			92.5%		93.9%		92.5%		91.3%		87.7%		89.2%
	Standard deviation			4.6		4.7		2.2		2.6		4.8		2.9

SH = Shuttle SL = Shuttleless
*Average of 4 tests

TABLE 11. Tensile Elongation (%) After Accelerated Weathering (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6 SH %	Nylon 6,6 SH % of Orig.	Nylon 6,6 SL %	Nylon 6,6 SL % of Orig.	Nylon 6 SH %	Nylon 6 SH % of Orig.	Nylon 6 SL %	Nylon 6 SL % of Orig.	Polyester SH %	Polyester SH % of Orig.	Polyester SL %	Polyester SL % of Orig.
VI	none		27.4	98.9	26.4	93.6	31.6	98.4	32.0	89.1	22.0	90.9	20.8	92.8
	resin		26.6	92.4	25.0	87.4	29.5	95.2	29.7	93.7	22.2	88.4	23.7	89.4
VIII	none		28.8	91.1	29.4	96.1	33.6	101.2	33.2	103.8	22.2	96.1	23.0	93.5
	resin		26.3	86.8	28.9	90.3	29.8	85.9	30.7	91.6	23.4	101.0	24.9	96.5
X	none		31.0	91.2	32.9	104.4	34.1	106.9	36.1	103.7	22.5	100.0	22.9	95.0
	resin		31.2	89.6	34.1	110.4	31.2	102.0	33.4	99.4	22.9	93.1	23.9	107.2
XIII	none		26.9	95.1	31.9	104.2	33.4	97.7	34.5	98.0	22.0	92.1	24.9	95.8
	resin		27.9	94.2	31.3	117.7	31.4	97.2	30.0	91.7	21.9	92.4	24.9	96.9
XIX	none		28.1	87.5	31.4	108.6	30.3	109.4	30.9	104.4	23.0**	86.7	23.0	90.9
	resin		28.2	89.8	29.9	105.6	28.1	104.1	31.3	102.3	22.4	86.8	23.3	95.9
XXII	none		29.9	96.4	31.1	102.6	27.8	104.1	27.6	95.8	22.9	94.6	22.1	87.7
	resin		30.3	104.5	30.4	98.7	30.0	99.7	29.7	96.4	23.9	96.4	22.8	91.2
	Average of all values			93.1%		101.6%		100.2%		97.5%		93.2%		94.4%
	Standard deviation			5.1		8.8		6.1		5.3		4.7		5.0
	Average of uncoated			93.4%		101.6%		103.0%		99.1%		93.4%		92.6%
	Standard deviation			4.2		5.6		4.7		6.1		4.6		3.0
	Average of resin coated			92.8%		101.7%		97.4%		95.9%		93.0%		96.2%
	Standard deviation			6.2		11.7		6.5		4.3		5.2		6.2

SH = Shuttle SL = Shuttleless
*No spec given
**Average of 4 tests

TABLE 12. Energy Absorption (ft-lb/ft) After Accelerated Weathering (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6 SH ft-lb/ft	Nylon 6,6 SH % of orig.	Nylon 6,6 SL ft-lb/ft	Nylon 6,6 SL % of orig.	Nylon 6 SH ft-lb/ft	Nylon 6 SH % of orig.	Nylon 6 SL ft-lb/ft	Nylon 6 SL % of orig.	Polyester SH ft-lb/ft	Polyester SH % of orig.	Polyester SL ft-lb/ft	Polyester SL % of orig.
VI	none		315	86.3	272	75.3	336	77.4	363	69.5	255	82.5	220	83.6
	resin		281	68.4	253	66.0	340	77.3	340	73.9	257	79.6	244	86.8
VIII	none		480	77.4	496	76.8	558	78.9	606	90.8	403	88.0	405	87.9
	resin		447	69.2	499	72.8	485	69.6	532	70.6	403	92.6	440	86.6
X	none		1158	80.2	1187	105.0	1271	99.3	1375	96.3	847	103.9	943	94.1
	resin		1094	75.3	1175	100.5	1210	89.9	1235	87.9	841	86.6	922	101.4
XIII	none		754	81.2	981	100.4	936	85.7	1105	85.9	673	91.6	715	91.0
	resin		846	80.0	958	109.4	929	82.4	934	72.9	673	87.6	679	92.4
XIX	none		1276	75.6	1526	109.5	1299	106.1	1244	104.4	948**	75.3	871	83.7
	resin		1325	87.9	1383	102.3	1235	100.5	1260	94.1	905	76.0	927	88.2
XXII	none		1209	90.6	1257	97.4	1013	93.9	1054	80.9	880	91.2	858	79.2
	resin		1278	118.6	1199	86.6	1101	88.4	1234	85.9	934	90.6	933	84.3
	Average of all values			82.6%		91.8%		87.5%		84.4%		87.1%		88.3%
	Standard deviation			13.2		15.5		11.0		11.1		8.0		5.9
	Average of uncoated			81.9%		94.2%		90.2%		88.0%		88.8%		86.6%
	Standard deviation			5.6		14.7		11.5		12.2		9.6		5.5
	Average of resin coated			83.2%		89.6%		84.7%		80.9%		85.5%		90.0%
	Standard deviation			18.8		17.4		10.8		9.7		6.4		6.2

SH - Shuttle SL - Shuttleless
*No spec given
**Average of 4 tests

For all types (nylon 6,6 and nylon 6 and polyester), there is no significant difference between the average strength retention of shuttle and shuttleless constructions. Although there is a weathering specification for resin coated webbings only, the presence of the coating does not appear to affect weathering performance. Coated and uncoated webbings perform equivalently, as may be seen from the separate averages at the bottom of Table 10. At this level of exposure, coating cannot be considered to improve weathering performance.

For all webbing types, elongation remains close to the original value with some slight departures. The lowest elongation retention was 86.7% for Type XIX shuttle, uncoated polyester; and the highest retention was an increase to 117.7% for Type XIII shuttleless, resin coated nylon 6,6. The average values for each fiber type and weaving method were statistically equivalent.

Retention of energy absorption after accelerated weathering follows from the strength and elongation measurements. As noted previously, slight decreases in strength and elongation can bring reductions in energy which are, in a number of cases, in the 70 to 80% range. (A value as low as 66% was measured for the Type VI shuttleless, resin-coated nylon 6,6). The averages of each coated fiber type and weaving method, shown at the bottom of Table 12, range from 81 to 90% retention. As found for many other treatments, there are no significant differences in average behavior among fiber types or weaving methods.

7. Hex Bar Abrasion

All webbings were abraded 2500 cycles in the Hex Bar Abrader as specified in Method 5309 of Federal Standard 191A. This abrasion procedure involves both rubbing and flexing and can, in some instances, result in a phenomenon which we have called "napping," which is a roughening of the surface which is not in contact with the hex bar. This surface has many protruding yarn loops giving it the appearance of a napped fabric, and an increase in webbing thickness in the napped area. An example is given in Figure 76 which shows a Type XIX shuttle, uncoated, polyester. Figure 76a shows the original webbing cross section. Figure 76b shows the webbing after hex bar abrasion. The left side was in contact with the bar and shows some evidence of "normal" abrasion with broken or damaged fibers. The right side clearly shows large protruding loops, giving an overall thickness increase. Figure 76c shows the napped surface. In this case, the napping has occurred at the outer edges as evidenced by the long wavy loops. Warp yarns protruding from the webbing plane after abrasion were also observed by Gardella and Devarakonda [2]. They attributed this to a "raking" action which increased warp yarn crimp.

Napping has been studied in some detail [12]. It is caused by buckling of the warp yarns, and can be induced solely by flexing, without an additional rubbing component. Napping of the surface occurs only when the webbing construction happens to permit it. The critical parameters are the tightness of the weave and, more importantly, the relationship between the "wavelength" of the warp yarn twist and the weft yarn spacing. When a

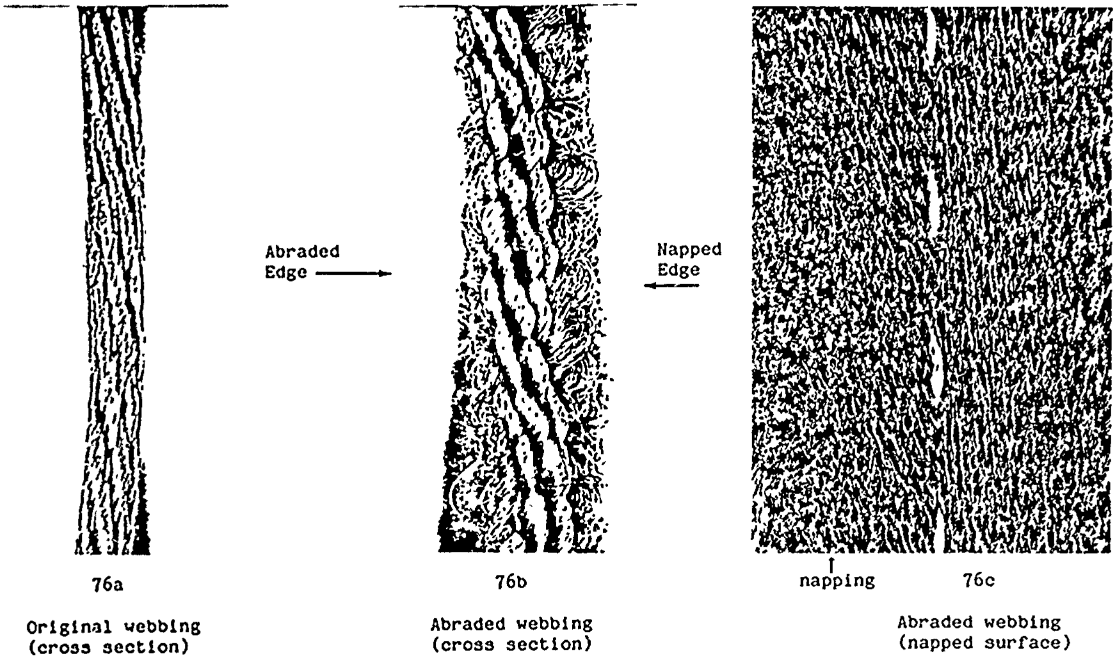

Figure 76. Illustration of Napping from Hex Bar Abrasion

match between these dimensions exists, and when the filament yarn span between restrictions (filling interlacings) is between certain limits, conditions for the development of warp yarn loops is optimum. The constructional limits within which this becomes clearly evident are relatively narrow, though it occurs to varying degrees over fairly broad limits.

Table 13 is a detailed example of these constructional factors for the uncoated, shuttle version of each weboing type. This illustrates the controlling factor is the number of warp yarn turns per weft yarn intersection. This is obtained by dividing the warp twist by the pick count, and then multiplying by a spacing factor dependent on the weave: 1 for the plain weave, or 2 for the 2 up 2 down twill. The double twill weaves of Types XIX and XXII are more complicated and an approximate value is given based on a factor of either 5 or 3, respectively.

Of these constructions, those with a greater number of turns per intersection show a greater tendency to form warp yarn loops. For the example given, webbings above approximately 0.3 turns between intersections (considering the higher factor in the more complex weaves) tend to nap. Table 14 describes the presence or absence of napping for all webbing types. The double plain weaves (Types X and XIII), with low turns between intersections, do not nap, while the twill weaves are more prone to napping. The polyester webbings, with slightly higher warp yarn twist and lower pick counts show an increased napping tendency. These results should not imply this is a characteristic of the polyester, as results would differ with different weave constructions.

Tensile strength, elongation and energy absorption were measured after hex bar abrasion. Results are shown in Tables 15, 16, and 17. Strength retention after hex bar abrasion is generally good. There is a specification value of 80% original tensile strength retention for all resin coated samples; and for one uncoated sample (Type XXII), a value of 90% of the minimum original tensile strength (as opposed to the measured original value). For all nylon 6,6 and nylon 6 webbings for which there is a specification, results are within spec. For the polyester webbings, three of the resin-coated versions are marginally below the spec. These are Type X shuttleless at 76.9%, Type XIII shuttleless at 74.0%, and Type XIX at 78.9%. The Type XXII uncoated polyester gave values far below the 90% spec at 56.4 and 43.4% for shuttle and shuttleless webbings, respectively. Two general observations may be made from these strength data. First, there is no statistically significant difference for any webbing material (nylon 6,6, nylon 6 or polyester) between the average shuttle and shuttleless constructions in their resistance to tensile strength reduction by hex bar abrasion. Secondly, the Type XXII uncoated webbings, while being uniquely subjected to a 90% of minimum spec, in comparative testing, perform similarly to the other uncoated webbings when normalized to original measured values.

TABLE 13. Example of Constructional Factors in Napping

Uncoated, Shuttle Webbings

Webbing Type	Fiber Type	Warp Twist (tpi)	Ends/ Warp	Picks/ Inch	tpi/ ppi	Turns Between Intersections	Napping Tendency
VI	Nylon 6,6	2.7	114	22	.123	.246	O
2 up 2 down	Nylon 6	2.9	114	22	.132	.264	O
Herringbone twill	Polyester	3.3	114	20	.165	.330	N+
VIII	Nylon 6,6	2.7	166	18	.150	.300	N-
2 up 2 down	Nylon 6	2.9	166	19	.153	.306	N
Herringbone twill	Polyester	3.3	165	15	.220	.440	N+
X	Nylon 6,6	2.7	258	22	.123	.123	O
Double	Nylon 6	2.9	257	24	.120	.120	O
plain	Polyester	3.4	257	16	.213	.213	O
XIII	Nylon 6,6	2.7	284	24	.113	.113	O
Double	Nylon 6	2.9	277	26	.112	.112	O
plain	Polyester	3.4	282	18	.189	.189	O
XIX	Nylon 6,6	2.7	282	18	.150	.150	N
5 up 1 down						.750	
twill	Nylon 6	2.9	280	20	.145	.145	N+
						.725	
	Polyester	3.3	280	14	.236	.236	N+
						1.18	
XXII	Nylon 6,6	2.8	264	18	.156	.156	O
(1/3 twill)						.468	
	Nylon 6	2.9	259	19	.152	.152	N
						.456	
	Polyester	3.5	259	14	.250	.250	N
						.750	

O = No napping

N⁻ = Slight napping

N = Napping

N+ = Extensive napping

TABLE 14. Occurrence of Napping after Hex Bar Abrasion

Webbing Type	Treatment	Nylon 6,6		Nylon 6		Polyester	
		SH	SL	SH	SL	SH	SL
VI	none	0	0	0	0	N+	N+
	resin	0	0	0	0	0	0
VIII	none	N⁻	N⁻	N	N	N+	N+
	resin	N	N	0	N	0	0
X	none	0	0	0	0	0	0
	resin	0	0	0	0	0	0
XIII	none	0	0	0	0	0	0
	resin	0	0	0	0	0	0
XIX	none	N	N	N+	N	N+	N+
	resin	N	0	0	N	0	0
XXII	none	0	0	N	0	N	N
	resin	0	0	0	0	0	0

SH = Shuttle SL = Shuttleless

0 = no "napping"

N+ = extensive "napping"

N = "napping"

N⁻ = slight "napping"

TABLE 15. Tensile Strength (lb) After Hex Bar Abrasion (average of 5 values)

Webbing Type	Treatment	Spec (% of original)	Nylon 6,6 SH lb	Nylon 6,6 SH % of original	Nylon 6,6 SL lb	Nylon 6,6 SL % of original	Nylon 6 SH lb	Nylon 6 SH % of original	Nylon 6 SL lb	Nylon 6 SL % of original	Polyester SH lb	Polyester SH % of original	Polyester SL lb	Polyester SL % of original
VI	none		3317	96.2	3124	91.5	3219	95.6	3164	90.8	999	33.2	1466	57.0
	resin	80	3240	92.3	3123	92.3	3169	93.1	3189	92.7	2590	86.2	2022	82.2
VIII	none		4863	95.0	4820	92.1	4667	94.6	4641	94.4	2001	43.3	2099	46.0
	resin	80	4406	86.7	4697	92.0	4754	97.6	4698	92.8	4317	95.5	4405	93.7
X	none		10095	90.1	10506	99.8	10005	92.9	9615	86.3	4973	58.5	4646	46.6
	resin	80	10334	91.9	9712	88.1	10237	91.8	10085	90.0	8099	86.5	7984	76.9*
XIII	none		7342	84.5	7587	88.1	7324	86.6	7469	86.1	4224	57.8	4299	59.3
	resin	80	7765	86.8	6960	80.0	7422	87.9	7498	85.7	6208	83.0	5194	74.0*
XIX	none		6210	48.8	7651	61.5	7175	60.1	6424	56.7	4292	35.4	4381	42.9
	resin	80	9942	80.7	11541	94.6	11690	97.7	10471	88.4	11065	94.1	8280	78.9*
XXII	none		9496	82.9	9665	87.1	8713	81.7	8825	79.2	5364	55.1	4126	38.7
	(90% of 9500)**			(100.0)		(101.7)		(91.7)		(92.9)		(56.4)*		(43.4)*
	resin	80	10667	96.7	10695	94.4	10443	96.4	10407	92.7	9487	91.7	8928	82.6
	Average of all values			86.1%		88.5%		89.7%		86.3%		68.4%		64.9%
	Standard deviation			12.8		9.8		10.5		10.2		23.6		18.6
	Average of uncoated			82.9%		86.7%		85.3%		82.3%		47.2%		48.4%
	Standard deviation			17.6		13.1		13.4		13.5		11.4		8.1
	Average of resin coated			89.2%		90.2%		94.1%		90.4%		89.5%		81.4%
	Standard deviation			5.6		5.5		3.9		2.9		5.0		6.9

SH - Shuttle SL - Shuttleless
*- Off spec
**Numbers in parentheses are strengths expressed as a percentage of 9500 lb, the applicable minimum strength for this type

TABLE 16. Tensile Elongation (%) After Hex Bar Abrasion (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6				Nylon 6				Polyester			
			SH		SL		SH		SL		SH		SL	
			%	% of original	%	% of original	%	% of original	%	% of original	%	% of original	%	% of original
VI	none		25.9	93.5	25.0	88.6	31.0	96.6	31.4	87.5	18.5	76.4	19.8	88.4
	resin		25.9	90.0	25.1	87.8	28.7	92.6	29.4	92.7	22.1	88.0	23.6	89.0
VIII	none		28.0	88.6	27.7	90.5	32.6	98.2	30.8	96.3	22.1	95.7	19.9	80.9
	resin		22.9	75.6	26.5	82.8	31.4	90.5	29.8	89.0	23.9	103.0	24.6	95.3
X	none		29.8	87.6	30.4	96.5	33.0	103.4	34.3	98.6	26.4	117.3	24.5	101.7
	resin		29.0	83.3	29.3	94.8	30.3	99.0	29.9	89.0	23.6	95.9	24.2	108.5
XIII	none		25.9	91.5	29.6	96.7	34.7	101.5	34.5	98.0	29.4	123.0	22.9	88.1
	resin		25.1	84.8	27.0	101.5	29.3	90.7	27.9	85.3	22.4	94.5	24.7	96.1
XIX	none		21.5	67.0	25.8	89.3	21.8	78.7	24.8	83.8	21.2	80.0	21.9	86.6
	resin		24.6	78.3	26.2	92.6	26.5	98.1	29.7	97.1	25.7	99.6	22.2	91.4
XXII	none		25.4	81.9	26.9	88.8	22.8	85.4	24.2	84.0	21.2	87.6	19.6	77.8
	resin		27.4	94.5	28.0	90.9	28.1	93.4	28.0	90.9	24.8	100.0	24.6	98.4
	Average of all values			84.7%		91.7%		94.0%		91.0%		96.8%		91.9%
	Standard deviation			8.1		5.0		7.0		5.5		13.6		8.7
	Average of uncoated			85.0%		91.7%		94.0%		91.3%		96.7%		87.3%
	Standard deviation			9.7		3.8		9.8		7.0		19.4		8.3
	Average of resin coated			84.4%		91.7%		94.1%		90.7%		96.8%		96.5%
	Standard deviation			7.1		6.3		3.7		4.0		5.3		6.8

SH - Shuttle SL - Shuttleless
*No spec given

TABLE 17. Energy Absorption (ft-lb/ft) After Hex Bar Abrasion (average of 5 values)

			Nylon 6,6				Nylon 6				Polyester			
			SH		SL		SH		SL		SH		SL	
Webbing Type	Treatment	Spec*	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.
VI	none		300	82.2	273	75.6	368	84.8	374	71.6	88	28.5	149	56.7
	resin		321	78.3	296	76.9	371	84.3	365	79.3	255	78.9	226	80.4
VIII	none		515	83.1	495	76.6	581	82.2	540	81.0	204	44.5	217	47.1
	resin		366	56.6	460	67.2	600	86.1	569	75.6	431	99.1	450	88.6
X	none		1055	73.2	1091	96.5	1246	97.3	1232	86.3	608	74.6	473	47.2
	resin		1078	74.2	1006	86.1	1229	91.3	1136	80.9	855	88.1	854	93.9
XIII	none		564	71.4	828	84.7	986	90.3	1012	78.7	582	79.2	440	56.0
	resin		733	69.2	693	79.1	815	72.3	788	61.5	607	79.0	562	76.5
XIX	none		589	34.9	851	61.1	542	44.3	557	46.8	426	33.8	443	42.6
	resin		961	63.8	1132	83.7	1218	99.2	1172	87.5	1130	94.9	802	76.3
XXII	none		848	63.5	935	72.4	701	65.0	753	57.8	582	60.3	403	37.2
	resin		1096	101.7	1125	81.3	1091	87.6	1146	79.7	1002	97.2	934	84.4
	Average of all values			71.0%		78.4%		82.1%		73.9%		71.5%		65.6%
	Standard deviation			16.3		9.2		15.2		12.4		24.4		19.8
	Average of uncoated			68.1%		77.8%		77.3%		70.4%		53.5%		47.8%
	Standard deviation			17.8		11.9		19.4		15.2		21.2		7.6
	Average of resin coated			74.0%		79.1%		86.8%		77.4%		89.5%		83.4%
	Standard deviation			15.6		6.7		8.9		8.7		9.0		7.0

SH - Shuttle SL - Shuttleless
*No spec given

For those uncoated webbings for which there are no specification values, the uncoated polyester webbings generally show significantly greater strength reductions after hex bar abrasion than either nylon 6,6 or nylon 6. This may be seen more clearly when the averages are separated into two groups, uncoated and coated, at the bottom of Table 15. The low strength retention values after hex bar abrasion for the uncoated polyester webbings cannot be directly attributed to the inherent abrasion properties of the fiber, but are much more likely caused by the construction. As noted previously, these polyester constructions are often lower in end or pick counts and are thus somewhat more flexible. This increased flexibility makes them more subject to the flexing action of the abrader. Presumably, the resin coating acts to immobilize the webbing and the coated polyester webbing average values are much closer to the nylon 6,6 and nylon 6.

Considering the strength retention results in light of the napping phenomenon discussed above, those constructions which exhibit napping generally show the most strength reduction. However, this is neither a necessary nor a sufficient condition for strength reduction, as several samples show 50% retention with no napping and others show 80 to 90% with napping. Resin coating, in most all cases, reduces the tendency to nap by immobilizing an otherwise mobile structure. This is particularly evident in Type XIX which is a 5 up 1 down twill weave which naps, sometimes extensively, for all webbings in the uncoated state, and is eliminated in all but two of the resin-coated versions (see Table 14).

Elongation values after hex bar abrasion are given in Table 16. Elongation is generally comparable to the original tensile elongation, with overall averages for each material type and construction method ranging from 85 to 97% of original. There are no statistically significant differences among fiber types (nylon 6,6, nylon 6 or polyester) or between weaving methods (shuttle or shuttleless) in average elongation retention. Within the individual webbings, however, results are quite variable, ranging from 67% for a Type XIX, shuttle, uncoated nylon 6,6 to 123% for a Type XIII, shuttleless, uncoated polyester.

The relation between napping and elongation is somewhat more clearly defined than that for tensile strength. All samples that showed residual elongations of <80% displayed napping, and all samples that showed greater than 100% elongation did not. Napping is not always sufficient to significantly reduce elongation, however, as napped values ranged from 67 to 98% of original. One potential reason for the decrease in elongation with napping is a structural rearrangement which, on tensioning, produces a strain imbalance. Because of this imbalance, not all of the warp yarn loops can be pulled straight and premature failure results. For all uncoated polyester webbings, regardless of napping, the load-elongation curves after hex bar abrasion are shifted to the right, to higher elongations at equivalent loads (see, for example, Figures 12 and 13). This shift is presumably caused by structural rearrangement during flexing of the mobile polyester constructions. Some, but not necessarily all, of these rearrangements are pulled free during tensioning, leading to premature failure in some cases. However, the exact nature of these changes would require more careful study to explain fully.

Energy absorption after hex bar abrasion is shown in Table 17. As observed for tensile strength and elongation, there is no significant effect of shuttle vs. shuttleless construction, and notably for the polyester webbings, resin coating is particularly effective in raising the measured values. When considering only the averages of resin coated samples, the polyester constructions show energy absorption retention comparable to either nylon 6,6 or nylon 6. One point should be noted on energy absorption. As energy absorption is the product of strength and elongation, a small reduction in tensile strength (still within the 80% original spec) along with a small reduction in elongation can result in substantially reduced energy absorption. Many values of energy absorption for all material types fall within the 60 to 70% range. Again, the importance of energy absorption values to actual use should be interpreted with care.

8. <u>High Speed Impact</u>

Results for tensile strength, elongation and energy absorption after high speed impact cycling are shown in Tables 18, 19 and 20. Webbings were subjected to 5 impact cycles to 50% of the original measured breaking energy, and then tested to failure in a regular, slow speed, tensile test. Impact cycles and tensile testing were conducted on coated webbings only. Nylon 6,6, nylon 6, and polyester webbings all showed excellent strength retention after cycling. All webbings, regardless of fiber type or weaving method, retained >94% of original strength, with averages for each fiber type and weaving method ranging from 97 to 100%. There were no significant differences among nylon 6,6, nylon 6, or polyester nor between shuttle and shuttleless constructions.

Values for elongation after impact are quite variable, as shown in Table 19. Averages for all types within the nylon 6 shuttle and shuttleless constructions, and within the nylon 6,6 shuttleless are greater than 90%. Individual types within these sets range from 85 to 105% elongation retention. The nylon 6,6 shuttle webbings retain, on average, 84% of original elongation, because of the variability in these results, however, it is not possible to conclude that the nylon 6,6 shuttle constructions are significantly different from the shuttleless or nylon 6 constructions.

Elongation of polyester webbings after impact show a significant drop. They retain, on average, 75 and 76% of original for shuttle and shuttleless webbings, respectively, with no significant difference in the behavior between the two weaving methods. Examination of the load-elongation curves for the coated polyester webbings suggests a reason for this drop in elongation. All curves after impact cycling show a pronounced reduction of the inflection point, or shoulder, observed in the original polyester curves (see, for example, Figure 14 and 15). This inflection point is normally associated with crimp interchange. Potentially, a sizable component of the initial elongation in the polyester webbings results from crimp interchange during tensioning, rather than straining of the individual fibers. It is this component which is exhausted during impact cycling. If crimp interchange is a significant factor, then the less than optimum constructions of the polyester webbings make it impossible to form any conclusions on the inherent impact resistant properties of the constituent polyester fibers.

TABLE 18. Tensile Strength (lb) After Impact Cycling (average of 5 values)

Webbing Type	Treatment	Original Spec (min)	Nylon 6,6 SH lb	Nylon 6,6 SH % of Orig.	Nylon 6,6 SL lb	Nylon 6,6 SL % of Orig.	Nylon 6 SH lb	Nylon 6 SH % of Orig.	Nylon 6 SL lb	Nylon 6 SL % of Orig.	Polyester SH lb	Polyester SH % of Orig.	Polyester SL lb	Polyester SL % of Orig.
VI	resin	2500	3370	96.0	3299	97.5	3382	99.3	3415	99.3	3029	100.9	2416	98.2
VIII	resin	4000	4942	97.2	4954	97.0	4784	98.2	4945	97.7	4582	101.4	4567	97.1
X	resin	9500	10640	94.6	10623	96.4	10856	97.3	10839	96.7	9234	98.6	9860	95.0
XIII	resin	7000	8679	97.0	8539	98.1	8272	97.9	8562	97.8	7271	97.2	6682	95.2
XIX	resin	10000	11921	96.8	11950	97.9	11740	98.1	11584	97.8	11866	100.9	10216	97.3
XXII	resin	9500	10864	98.5	11075	97.7	10425	96.3	10747	95.7	10227	98.8	10657	98.6
	Average values			96.7%		97.4%		97.8%		97.5%		99.6%		96.9%
	Standard deviation			1.3		0.6		1.0		1.2		1.7		1.5

SH = Shuttle SL = Shuttleless

TABLE 19. Tensile Elongation (%) After Impact Cycling (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6 SH %	Nylon 6,6 SH % of Orig.	Nylon 6,6 SL %	Nylon 6,6 SL % of Orig.	Nylon 6 SH %	Nylon 6 SH % of Orig.	Nylon 6 SL %	Nylon 6 SL % of Orig.	Polyester SH %	Polyester SH % of Orig.	Polyester SL %	Polyester SL % of Orig.
VI	resin		23.7	82.3	24.6	86.0	28.2	91.0	29.6	93.4	16.3	64.9	16.8	63.4
VIII	resin		24.5	80.9	27.3	85.3	30.2	87.0	30.3	90.4	17.9	77.2	17.3	67.1
X	resin		27.9	80.2	30.0	97.1	29.8	97.4	30.0	89.3	19.8	80.5	20.1	90.1
XIII	resin		25.8	87.2	27.8	104.5	30.6	94.7	30.0	91.7	18.3	77.2	20.5	79.8
XIX	resin		24.9	79.3	27.2	96.1	27.7	102.6	30.7	100.3	19.2	74.4	18.6	76.5
XXII	resin		26.7	92.1	28.8	93.5	26.7	88.7	26.2	85.1	18.4	74.2	19.3	77.2
	Average values			83.7%		93.8%		93.6%		91.7%		74.7%		75.7%
	Standard deviation			5.0		7.3		5.8		5.1		5.3		9.5

SH = Shuttle SL = Shuttleless
*No spec given

TABLE 20. Energy Absorption (ft-lb/ft) After Impact Cycling (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6				Nylon 6				Polyester			
			SH		SL		SH		SL		SH		SL	
			ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.
VI	resin		304	74.1	311	80.8	399	90.7	424	92.2	214	66.3	181	64.4
VIII	resin		467	72.2	525	76.6	605	86.8	663	88.0	370	85.1	360	70.9
X	resin		1093	75.2	1140	97.5	1307	97.1	1247	88.8	858	88.4	873	96.0
XIII	resin		875	82.6	926	105.7	1055	93.6	1152	89.9	609	79.3	603	82.0
XIX	resin		1170	77.6	1237	91.5	1321	107.6	1363	101.8	1055	88.6	852	81.1
XXII	resin		1124	104.3	1263	91.3	1117	89.7	1187	82.6	874	84.8	922	83.3
	Average values			81.0%		90.6%		94.3%		90.6%		82.1%		79.6%
	Standard deviation			12.0		10.7		7.4		6.4		8.4		10.9

SH = Shuttle SL = Shuttleless
*No spec given

Energy absorption after impact is shown in Table 20. Because of the drops observed in strength and elongation, average values of energy for each weaving method and fiber type show moderate reductions ranging from 80 to 94%. Because of the relatively high variability in these measurements, however, the absolute value of these reductions, and particularly the significance of differences between them, must be interpreted with caution.

One additional feature of the impact testing which should be pointed out, is that the impact energy applied to each webbing is based on the original measured breaking energy. Accordingly, those webbings with lower original breaking energy, for example many of the polyester constructions, received lower impact energies. This factor should be considered in any further interpretations of this data.

9. Edge Abrasion

During use within a harness system, the edges of a parachute webbing are exposed to a variety of hardware components. As the webbing travels back and forth within the hardware, the ability to withstand repeated abrasive cycling at its edges could become an important factor in performance. In particular, any differences in the edge construction, such as the presence or absence of a catch-cord in shuttleless or shuttle weaving should be considered. For this reason, a test method was designed to subject the webbing edge to a moderate degree of abrasive wear, producing a small, but noticeable degree of damage, and webbings were subsequently tested for changes in tensile properties.

As described in the Test Methods section, webbings were abraded, in sets of five, for one minute on each edge. Prior to tensile testing, a visual assessment was made of the number of yarns abraded from each edge. These results are given in Table 21. For the shuttleless webbings, two values are given; the first for the non-catch-cord edge, and the second for the catch-cord edge. Values ranged from 1/2 to 4 yarns abraded at either edge. Although this is a rather qualitative measure, there appeared to be no significant differences between shuttle and shuttleless webbings, or between the catch-cord and non-catch-cord edges of the shuttleless webbings.

Tensile properties, after one minute abrasion on each side, are shown in Tables 22, 23 and 24. Strength retention after abrasion ranges from 80 to 100% of original. The thinner, lighter weight webbings (Types VI and VIII) generally show the most strength loss after abrasion, from 80 to 93%. The most likely reason is that, for the thinner webbings, loss of a single yarn represents a larger fraction of the total load-bearing members. Also, thinner webbings experience an increased stress at the edge, as a smaller cross section must support the same normal load. The thinner webbings tend to lose more threads during abrasion, as shown in Table 21, but this is only a very general trend, and no direct correlation can be observed for all cases between the number of threads abraded and strength loss. There are no significant differences observed between the average strength retention of shuttle vs. shuttleless constructions, or among fiber types.

TABLE 21. Number of Yarns Abraded After Edge Abrasion (range of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6		Nylon 6		Polyester	
			SH	SL**	SH	SL**	SH	SL**
VI	resin		1-3	2/1-2	2-3	2-3/2-3	3-4	2/2
VIII	resin		2-4	2/2-3	2	3/3	2-4	3/3
X	resin		½-1	½-1/½-2	½-1	½-1/1	1-3	½-2/1-2
XIII	resin		½-2	½-1/½-1	½-2	1-2/1	½-2	½-2/1-2
XIX	resin		½-2	1/½-2	½-2	½-2/½-2	½-1	½-1/½-1
XXII	resin		½-2	½-2/1-2	½-2	½-2/½-2	½-2	1/1-2

SH = Shuttle SL = Shuttleless

*No spec given

**For Shuttleless webbings, first value(s) is non-catch cord edge, second value(s) is catch cord edge.

TABLE 22. Tensile Strength (lb) After Edge Abrasion (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6				Nylon 6				Polyester			
			SH		SL		SH		SL		SH		SL	
			lb	% of orig.	lb	% of orig.	lb	% of orig.	lb	% of orig.	lb	% of orig.	lb	% of orig.
VI	resin		3085	87.9	2990	88.3	3030	89.0	3006	87.4	2445	81.4	2030**	82.6
VIII	resin		4695	92.4	4748	93.0	4480	91.9	4460	88.1	3780	83.6	3765**	80.1
X	resin		10380	92.3	10120	91.8	10620	95.2	10360	92.5	8519**	91.0	9375**	90.3
XIII	resin		8285	92.6	8455	97.2	8200	97.1	8140	93.0	6990	93.5	6680	95.2
XIX	resin		11620	94.3	11990	98.3	11440	95.6	11720	99.0	11520	98.0	10040	95.6
XXII	resin		10460	94.8	10840	95.7	10380	95.8	10600	94.4	9800	94.7	10800**	100.0
	Average values (%)			92.4		94.1		94.1		92.4		90.4		90.6
	Standard deviation			2.44		3.74		3.04		4.28		6.53		7.86

SH - Shuttle SL - Shuttleless
*No spec given
**Average of 4 values

TABLE 23. Elongation (%) After Edge Abrasion (average of 5 values)

Webbing Type	Treatment	Spec*	Nylon 6,6 SH %	Nylon 6,6 SH % of orig.	Nylon 6,6 SL %	Nylon 6,6 SL % of orig.	Nylon 6 SH %	Nylon 6 SH % of orig.	Nylon 6 SL %	Nylon 6 SL % of orig.	Polyester SH %	Polyester SH % of orig.	Polyester SL %	Polyester SL % of orig.
VI	resin		21.7	75.3	23.6	82.5	24.3	78.4	24.4	77.0	20.0	79.7	26.3**	99.2
VIII	resin		22.4	73.9	24.6	76.9	36.0	103.7	24.4	72.8	25.6	110.3	23.4**	90.7
X	resin		27.6	79.3	26.8	86.7	29.0	94.8	30.8	91.7	23.2**	94.3	24.8**	111.2
XIII	resin		24.4	82.4	26.6	100.0	31.2	96.6	26.6	81.3	24.6	96.3	25.6	99.6
XIX	resin		25.9	82.5	26.3	92.9	24.0	88.9	27.7	90.5	25.3	98.0	24.2	99.6
XXII	resin		26.9	92.8	28.1	91.2	26.4	87.7	27.4	89.0	23.6	95.2	23.5**	94.0
	Average values (%)			81.0		88.4		91.6		83.7		95.6		99.1
	Standard deviation			5.77		8.16		8.70		7.85		9.77		6.98

SH - Shuttle SL - Shuttleless

*No spec given

**Average of 4 values

TABLE 24. Energy Absorption (ft-lb/ft) After Edge Abrasion (average of 5 values)

			Nylon 6,6				Nylon 6				Polyester			
			SH		SL		SH		SL		SH		SL	
Webbing Type	Treatment	Spec*	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.	ft-lb/ft	% of orig.
VI	resin		255	69.9	254	66.0	297	67.5	259	56.3	220	68.1	237**	84.3
VIII	resin		393	60.7	429	62.6	720	103.3	417	55.4	425	97.7	390**	76.8
X	resin		103:	71.0	931	79.6	1112	82.6	1062	75.6	894**	92.1	983**	108.1
XIII	resin		797	75.3	822	93.8	1035	91.8	842	65.7	767	100.0	701	95.4
XIX	resin		1197	72.8	1143	84.5	1074	87.5	1218	91.0	1176	98.7	1026	97.6
XXII	resin		1057	98.1	1144	82.7	1030	82.7	1161	80.8	971	94.2	1022**	92.3
	Average values (%)			74.6		78.2		85.9		70.8		91.8		92.4
	Standard deviation			12.5		11.8		11.8		14.2		12.0		10.9

SH = Shuttle SL = Shuttleless

*No spec given

**Average of 4 values

Elongation after edge abrasion is given in Table 23. Values range from 73.9% to 111.2%, with most values falling between 75% and 95%. The general reduction in elongation most probably results from premature failure at slightly lower strengths. Because of the drop in both strength and elongation, the energy absorption values, given in Table 24, show average values for the three fiber types (nylon 6,6, nylon 6 and polyester) ranging from 70.8% to 92.4%, with fairly large variability within fiber types. Because of this variability, it is not possible to determine any significant differences between shuttle or shuttleless constructions. Of the three fibers, the polyester may be marginally better in energy absorption retention, related to a marginally higher elongation retention. As stated previously, this is not necessarily a feature of the polyester itself, but rather of the construction, which is generally looser and more flexible. However, the number of comparisons is small, and these observations should be considered with care.

V. CONCLUSIONS AND RECOMMENDATIONS

The primary goal of this study has been to compare the tensile properties of shuttle and shuttleless webbings. Tensile properties were compared originally and after various treatments to determine what effects, if any, the use of a shuttleless weaving method has on performance. From all of the results of this study, there were no significant performance differences detected between the shuttle and shuttleless weaving methods. Original tensile properties, and tensile properties after accelerated weathering, hex bar abrasion, impact cycling and edge abrasion are statistically equivalent for both weaving methods. This conclusion applies to tensile strength, tensile elongation and energy absorption at break. Of particular importance are the impact and edge abrasion properties. No evidence of the catch-cord edge "unzipping" with impact was observed, and no unusual susceptibility to edge abrasion of the catch-cord edge was detected. In all laboratory testing, Class 2 shuttleless webbings performed equivalent to Class 1 shuttle webbings. Based on these results, shuttleless webbings should be considered for use in Class 1 (critical life support) applications. However, as a final precaution, we would recommend actual drop testing of shuttle and shuttleless webbings before altering the Class 1 spec to include shuttleless webbings.

A second goal of this study was to compare the tensile properties of three fiber types: nylon 6,6, nylon 6, and polyester. Of these, only nylon 6,6 is currently approved for use in Class 1 webbings. From all results of this study, we found no significant differences in the behavior of nylon 6,6 and nylon 6. The original tensile properties and after accelerated weathering, hex bar abrasion, impact cycling, and edge abrasion were equivalent for the two fiber types. One difference between nylon 6,6 and nylon 6 not addressed in this study is the difference in melting point; 265°C for nylon 6,6 and 225°C for nylon 6. These temperatures are far in excess of any developed as a result of the testing in this study. The potential for heat buildup during use or exposure to adverse conditions should be examined, however, before considering these materials equivalent for field use.

For the polyester webbings, several significant differences were noted. However, these constructions were formed by straight substitution of 1000-denier polyester for 840-denier nylon, and not truly optimized for performance. Many of the differences observed could not be attributed directly to an inherent property of the polyester fiber, but could have been significantly affected by the construction. The most notable differences were: original elongation of most polyester webbings were about 75 to 85% of the equivalent nylon 6,6 shuttle webbings. This gave energy in the range of 65 to 85% of the nylon 6,6 shuttle webbings. Several individual coated polyester constructions showed comparatively low tensile strength values after accelerated weathering (<85%). Polyester webbings showed slightly increased napping tendency during hex bar abrasion, and in the uncoated state showed relatively large strength reductions compared to nylon 6,6 and nylon 6. After impact cycling, polyester webbings show considerable loss of tensile elongation and energy absorption. In all of these cases, it must be emphasized that constructional effects could explain some or all of the differences. Clearly, additional study of optimized polyester constructions is recommended.

In many of the results observed in this study, small decreases in tensile strength and elongation after various treatments can lead to significant decreases in energy absorption. It is the former, tensile strength retention, which is used in all current specifications. The importance of a change in energy absorption is not at all clear. The interpretation of energy absorption data could become even more important if webbings, for example polyester, are constructed to meet all tensile strength specifications but at a lower elongation, and consequently lower energy absorption. It is worth noting that Kevlar™ webbings have a very low elongation, and significantly lower energy absorption to break than nylon webbings, yet are totally satisfactory for use in parachutes. In view of this, it may be desirable to consider more carefully the meaning of the energy absorption values by analysis of the conditions occurring during use, and by actual field drops.

Many of the webbings studied exhibited the phenomenon called "napping." The occurrence of napping relates to the nature of the test which provides both abrasion and flex, and is dependent on the webbing construction. Most of the problems encountered from napping do not relate to fiber type, and could presumably be reduced by constructional changes.

As a final point, accelerated weathering by Xenon burner, as conducted in this study, provides weathering more closely approximating the exposure to natural sunlight, which is assumed to be the degradative agent in accelerated weathering. Because the Xenon arc more closely approximates the spectrum of natural sunlight and represents the most current technology as specified in ASTM D2565-79 for exposure of plastic specimens, this procedure should be considered as a replacement for the current carbon arc weathering requirement.

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APPENDIX

During the course of this study, ten additional webbings, produced by a polyester supplier, became available for impact testing. Through a modification of the existing contract, these webbings were tested on the impact cycling device at the Natick laboratories. The webbings and test time were furnished at no expense to the Government, and the impact results are supplied as a part of this Final Report. All test methods used for these results are the same as described in the Test Methods section of the main report.

The ten polyester webbing constructions are shown in Table 1A. These are the same types as in the main study, with one additional, Type XXVI. All webbings tested for impact cycling were resin coated. Webbings were tested in the normal manner for original tensile properties and then impact cycled for 5 cycles to 50% of the measured breaking energy. Results for tensile strength, elongation and energy absorption are shown in Tables 2A, 3A and 4A. All webbings show good retention of original tensile strength. Results range from 95 to 102% of original values. Three of the webbing types did give absolute values of strength which were below the specification value for an original webbing, however. Two of these (Type XII shuttle, and Type XXVI shuttleless) were below spec in the original values, and Type XIII shuttleless was only marginally above spec to start. From the limited number of comparisons available, there is no significant difference in tensile strength retention after impact between the shuttle and shuttleless constructions.

Tensile elongation after impact shows a significant drop. Shuttle and shuttleless constructions retained, on average, 78% and 77% of their original values, respectively. There again appeared to be no difference in behavior between the two construction methods, shuttle or shuttleless. Values were quite variable, however, ranging from 62.5 to 86.5% of original. The load-elongation curves shown in Figures 1A through 10A exhibit the same reduction of the original inflection point observed in the main report. As described in the main report, this inflection point is normally associated with crimp interchange. Potentially, a sizable component of the initial elongation in these webbings results from crimp interchange during tensioning, rather than straining of the individual fibers. It is this component which is exhausted during cycling, and is substantially influenced by the construction.

The loss of elongation after impact is also evident in the tensile energy absorption which, on average, is 79% or 80% of original shuttle or shuttleless constructions, respectively. Again there is no significant difference between shuttle and shuttleless types. However, the above observations are based on a very limited number of tests, and the absolute value of the reductions should be considered with care.

All of the above results are quite consistent with the polyester specimen results in the main report.

TABLE A-1. Additional Polyester Webbing Constructions

Webbing Type	Weaving Method: Shuttle	Weaving Method: Shuttleless
VI	X	X
VIII		X
X		X
XIII	X	X
XIX		X
XXII		X
XXVI	X	X

TABLE A-2. Additional Polyester Webbing Constructions

Tensile Strength (lb) After Impact Cycling
(average of 5 values)

Webbing Type*	Shuttle		Shuttleless	
		% Original		% Original
VI	3043	99.7	3103	101.0
VIII			4186	98.8
X			10040	102.4
XIII	6160	95.4	6980	97.3
XIX			10180	100.5
XXII			9690	99.4
XXVI	14630	100.2	15660	102.4
	Average	98.4%		100.3%
	Std Dev	2.6		1.9

*All webbings resin coated.

TABLE A-3. Additional Polyester Webbing Constructions

Tensile Elongation (%) After Impact Cycling
(average of 5 values)

Webbing Type*	Shuttle %	Shuttle % Original	Shuttleless %	Shuttleless % Original
VI	11.8	86.6	12.8	86.5
VIII			14.6	88.5
X			20.4	75.8
XIII	18.6	70.7	17.4	76.3
XIX			19.2	62.5
XXII			17.6	75.9
XXVI	17.2	77.5	19.6	73.7
	Average	78.3		77.0
	Std Dev	8.1		8.6

*All webbings resin coated.

TABLE A-4. Additional Polyester Webbing Constructions

Energy Absorption (ft-lb/ft) After Impact Cycling
(average of 5 values)

Webbing Type*	Shuttle	Shuttle % Original	Shuttleless	Shuttleless % Original
VI	169	82.6	182	81.7
VIII			282	85.4
X			864	85.0
XIII	521	71.3	522	76.0
XIX			889	69.6
XXII			778	80.0
XXVI	1055	82.2	1346	83.8
	Average	78.7		80.2
	Std Dev	6.4		5.7

*All webbings resin coated.

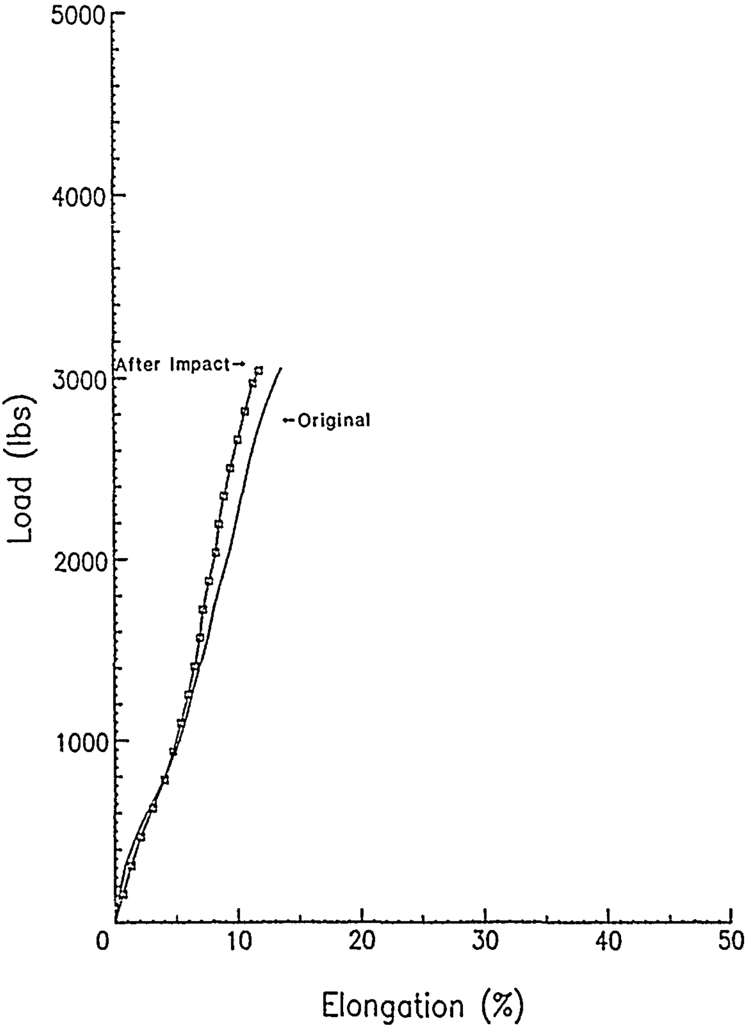

Figure A-1. Type 6, Class 1, Coated, Polyester Original Tensile and After Impact

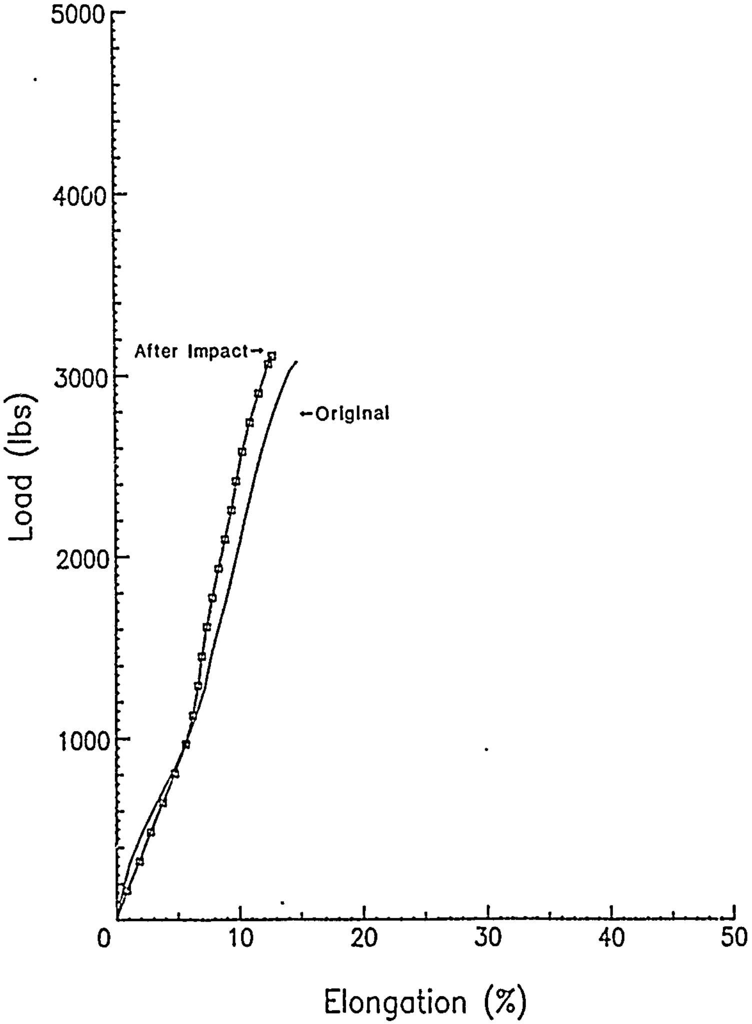

Figure A-2. Type 6, Class 2, Coated, Polyester
Original Tensile and After Impact

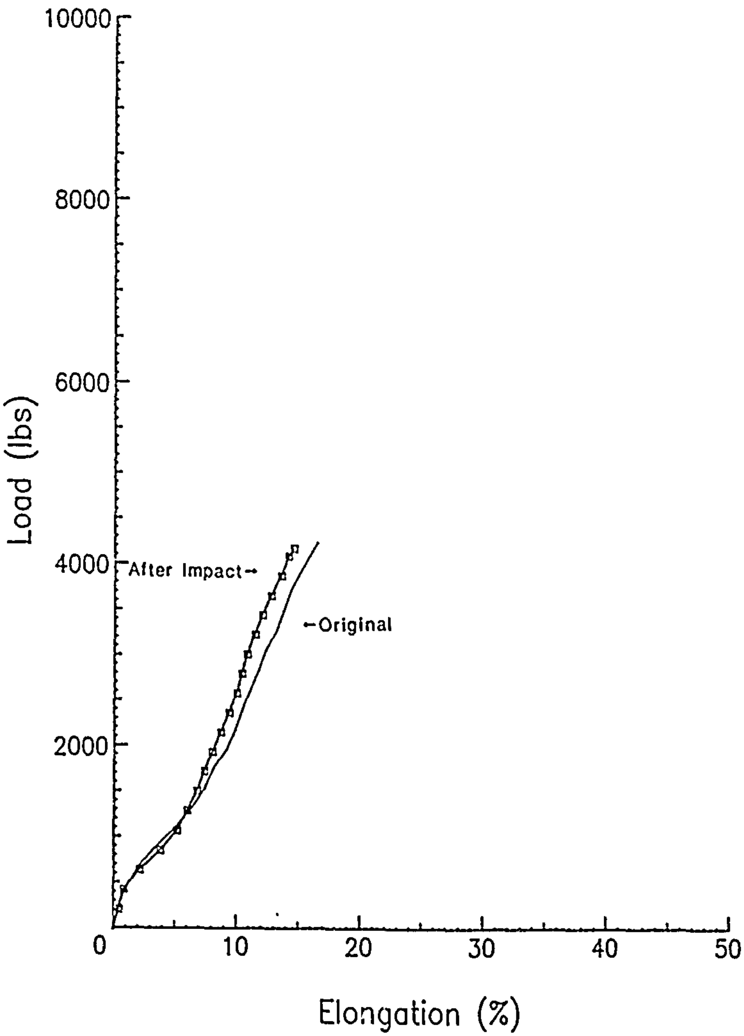

Figure A-3. Type 8, Class 2, Coated, Polyester
Original Tensile and After Impact

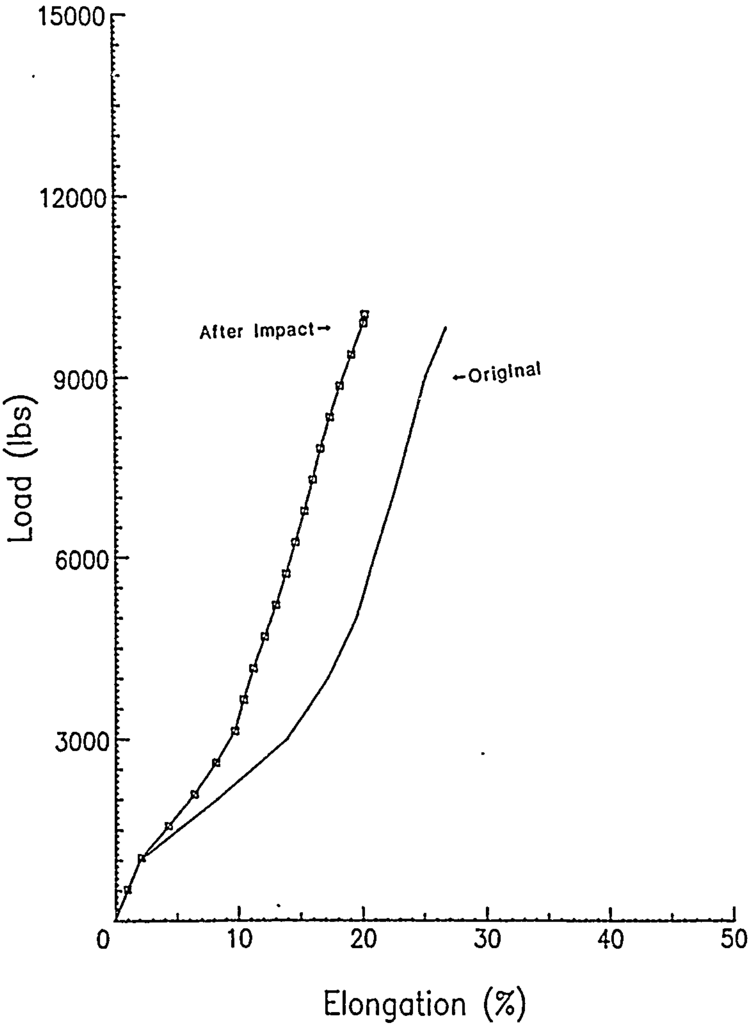

Figure A-4. Type 10, Class 2, Coated, Polyester Original Tensile and After Impact

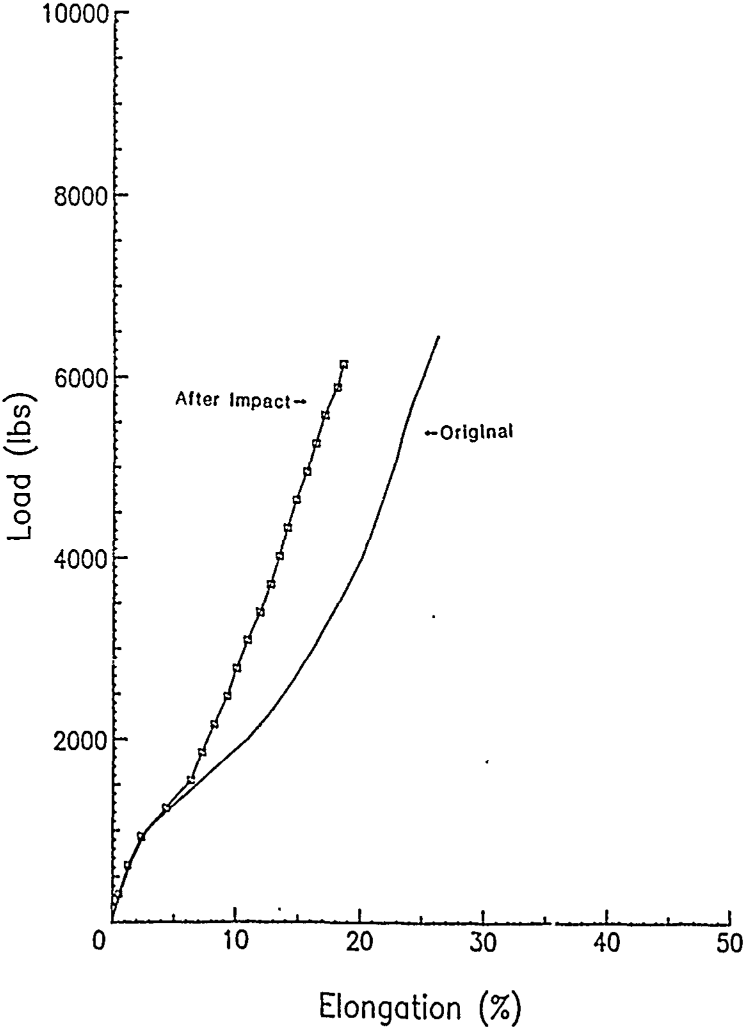

Figure A-5. Type 13, Class 1, Coated, Polyester Original Tensile and After Impact

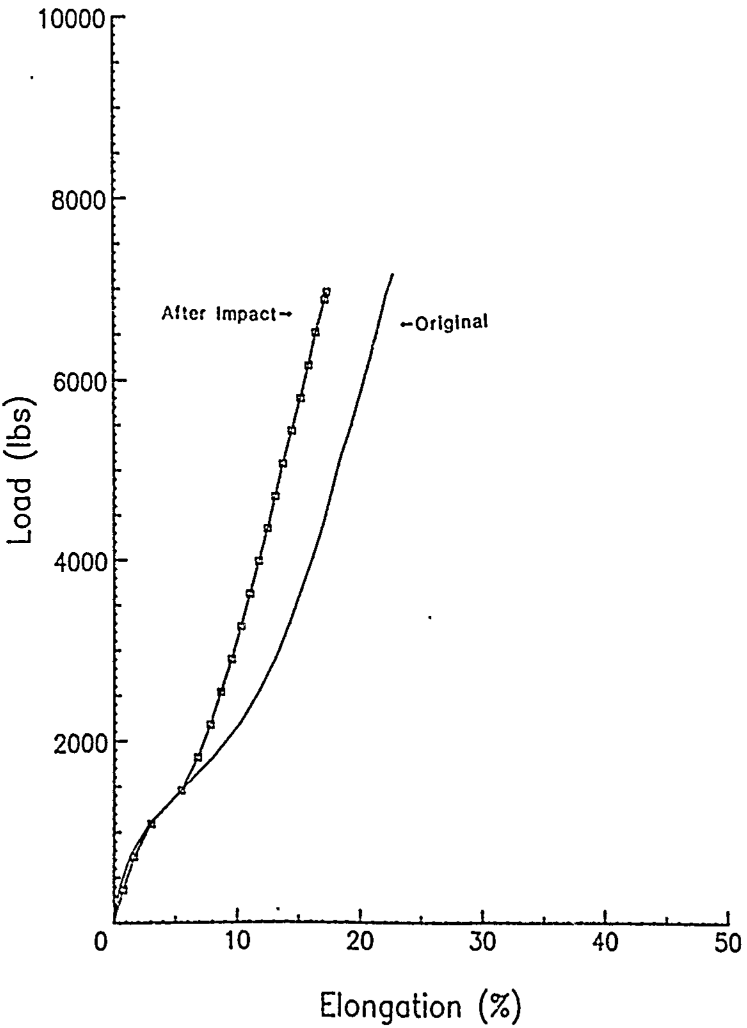

Figure A-6. Type 13, Class 2, Coated, Polyester
Original Tensile and After Impact

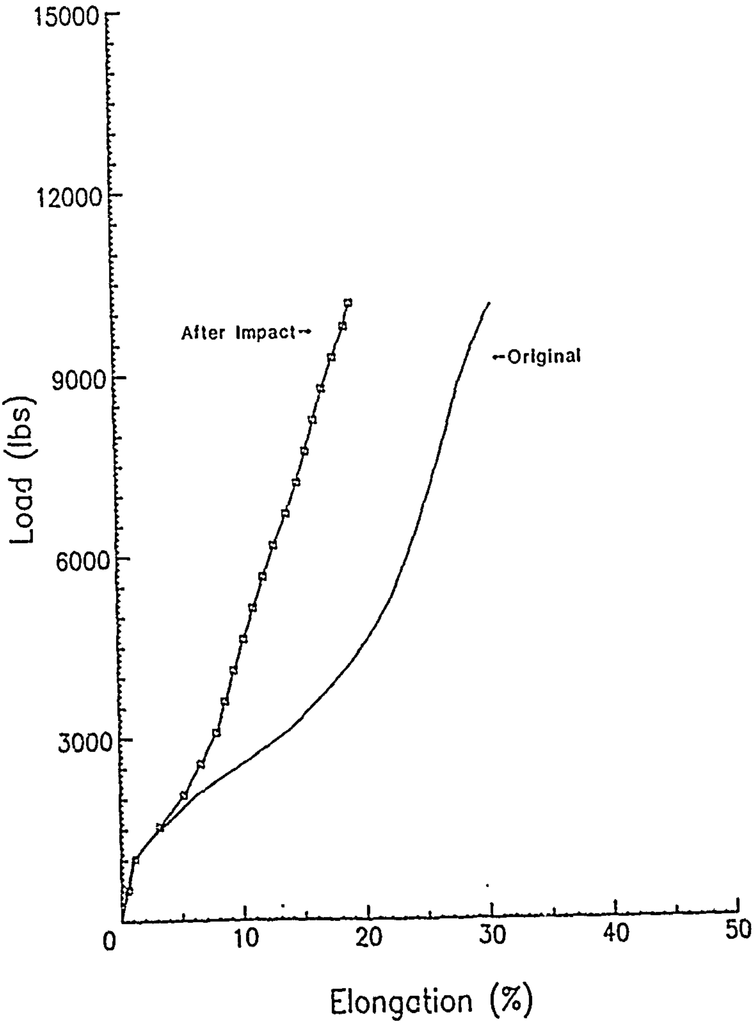

Figure A-7. Type 19, Class 2, Coated, Polyester Original Tensile and After Impact

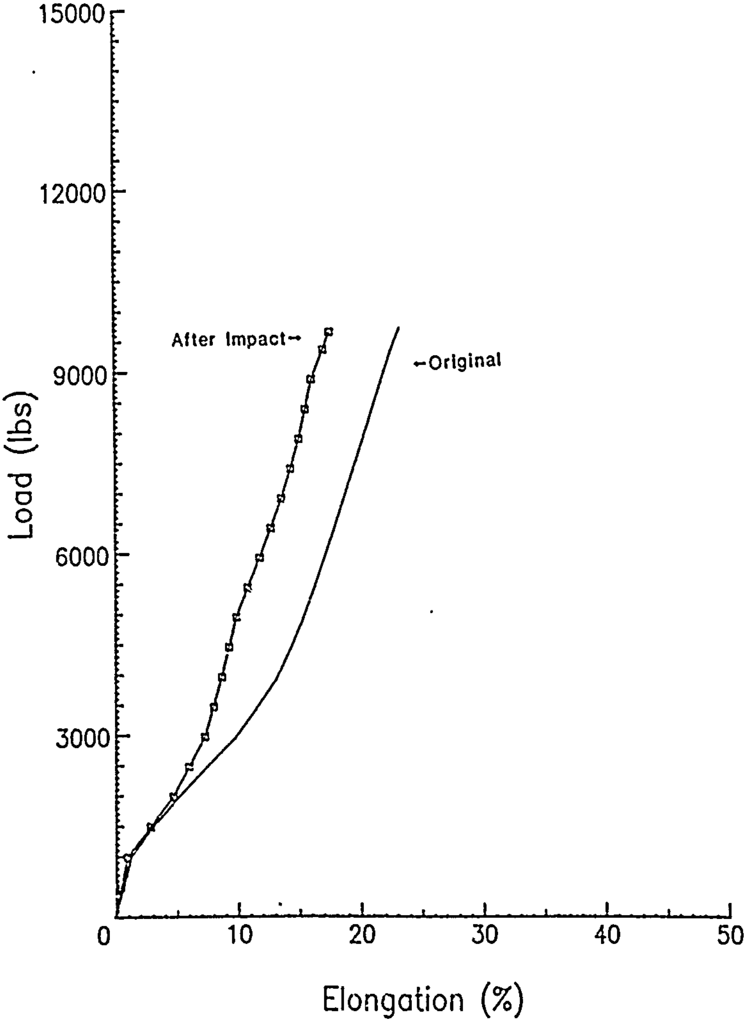

Figure A-8. Type 22, Class 2, Coated, Polyester Original Tensile and After Impact

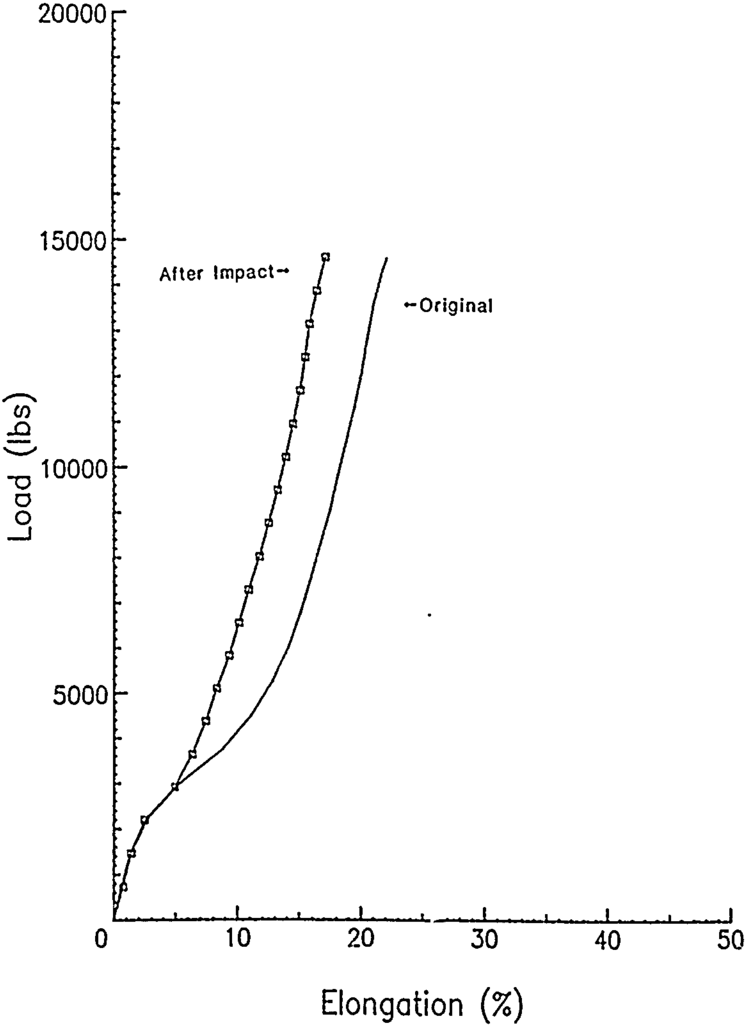

Figure A-9. Type 26, Class 1, Coated, Polyester
Original Tensile and After Impact

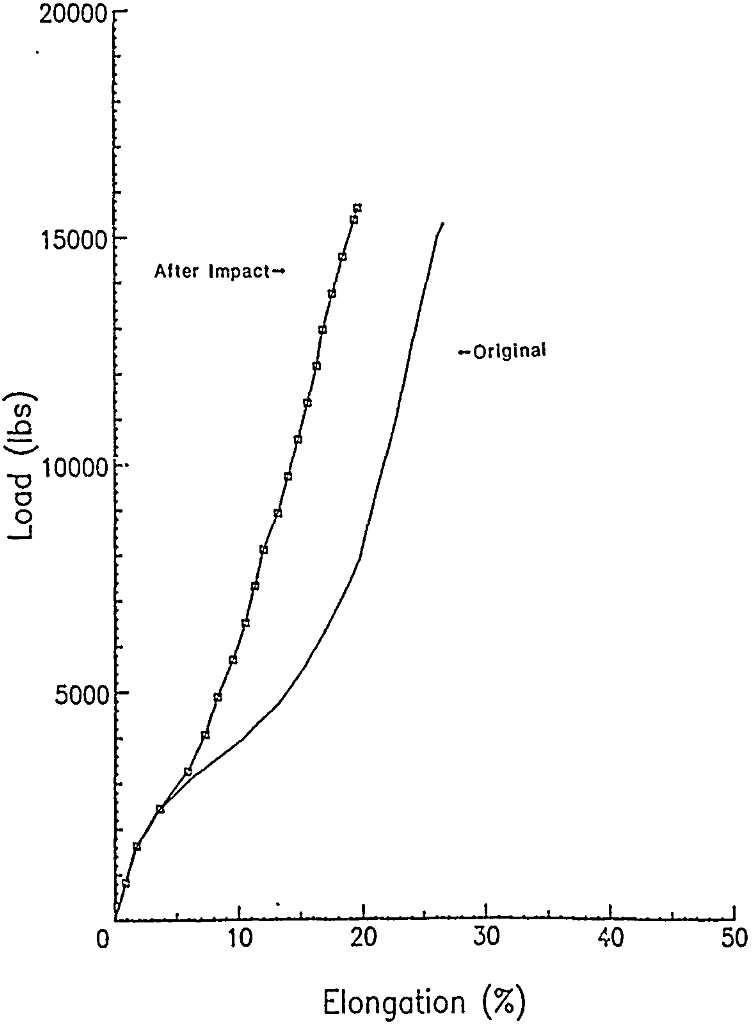

Figure A-10. Type 26, Class 2, Coated, Polyester
Original Tensile and After Impact