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TESTS OF BALLOON MATERIALS

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FOREWORD

This report is part of a series being prepared for the Materials Research Project of the NCAR Scientific Balloon Facility. The Materials Research Project is one of several technological development projects whose objectives are to extend the reliability and capabilities of scientific ballooning.

The National Center for Atmospheric Research (NCAR) is operated by the University Corporation for Atmospheric Research (UCAR) and sponsored by the National Science Foundation. NCAR was founded in 1960 to conduct and foster basic research in the atmospheric sciences in universities and research groups in the U. S. and abroad.

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Other reports being published in this balloon materials research series are:

FRB-2-64	Standard Test Methods for Balloon Materials.
FRB-3-64	Non-Standard Tests for Balloon Materials.

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TABLES AND ILLUSTRATIONS

F--Denotes foldout illustration.

TESTS OF BALLOON MATERIALS

1. INTRODUCTION

This test program was initiated early in 1963 as a survey of current and prospective materials that might be suitable as the barrier and/or structure for high altitude balloons. Films, coated fabrics and film-scrim composites were included in this program of almost 2000 tests. Some of the newer plastic and elastomeric materials were tested, even though they are not yet commercially available in quantity or cost suitable for balloon production. In some cases, different types and thicknesses of a given material were included in the tests.

Mechanical properties were evaluated at room temperature (25° C.) and at -80° C. (-112° F.). The tensile strength, elongation and modulus were determined, and tensile yield strengths were estimated from stress-strain data. Also measured were the forces for tear initiation and tear propagation.

In general, five replicate specimens were tested for each material and condition. The data have been analyzed and presented from a statistical viewpoint. The data are wholly inadequate for derivation of "design allowables" but the aggregation provides its intended purpose of identifying some sources of difficulty and opportunities for improvement.

2. MATERIALS TESTED

The test specimens are discussed below in "type" categories, describing the physical and chemical nature of each material. The data are later presented with the materials listed in alphabetical order and with a consistent numbering pattern.

2.1 Thermoplastic Films

Most thermoplastics can be extruded into wide lay-flat tubing, and this is the most appropriate form for economical fabrication of balloons. The tubing geometry also permits bi-axial stress orientation of the film, which is frequently of value. Polyethylene, polyethylene copolymer and polypropylene are available in tubing form. The other materials tested are presently available only as single flat films.

Polyethylene films were obtained from Visking Corporation and from Consolidated Thermoplastic Division of Rexall Drug and Chemical Company. These are but two of many film extruders and two of many more polyethylenes (variable density, melt index and molecular weight distribution). These samples were of low density and relatively low melt index, as indicated in Table 1. The Visqueen material was presumably of quality meeting MIL-P-4640A; the melt index of the Consolidated polyethylene was about double the MIL-spec. requirement.

Polyester films were also obtained from two sources: balloon quality Mylar was received from Schjeldahl and commercial polyester film from Minnesota Mining and Manufacturing Company.

There are several polypropylene films on the market, as well as propylene copolymers best known as polyolefins. Two polypropylene samples were tested in this program: slot cast film and biaxially oriented film, both by Union Carbide.

A fairly new ethylene copolymer film was tested--Consolidated S444. This polymer, apparently an ethylene-ethyl acrylate, is elastomeric at room temperature and is brittle at temperatures below -103° C. when tested by ASTM D746. The low modulus of this film was known to make it inappropriate as a structural material, but the presumed low temperature flexibility indicated prospects as a reinforced gas barrier.

Polyamide (nylon) films were tested early in the program, but were dropped for two reasons. The relatively high moisture absorption by nylon could create havoc in many atmospheric research projects. The same water absorption has a plasticizing action on the polymer, and mechanical properties vary with water content. Even though samples were conditioned in an atmosphere of 50 percent relative humidity, mechanical property changes were observed within the duration of testing in the laboratory where humidity was not controlled.

Polycarbonate film (Lexan and Merlon trade names) is a fairly new product with good strength, elongation and low temperature flexibility. These films, to date, are produced for electrical applications. Their mechanical properties may be improved in the near future, as applications broaden.

The sample of polyurethane film was produced by laboratory tube extrusion of Texin. This is a thermoplastic that has elastomeric mechanical properties. Some of the polyurethanes remain flexible to near liquid nitrogen temperature. The Texin sample showed many pin-holes and gel particles when it was inspected under polarized light.

2.2 Film-Filament Composites

Some current and prospective composites were tested in this program, using the same test methods as used for films.

The polyamide (nylon) parachute fabrics used by Raven were evaluated in two forms: Acryloid-coated fabric as used on hot-air balloons, and Mylar-laminated fabric as suitable for pressurized balloons. The effects of humidity change on the oriented nylon fabric were not apparent during this evaluation.

The Mylar-Dacron product, GT-12 by Schjeldahl was tested, along with a material of similar appearance--a nylon-polyester scrim, SLP 50441, by Minnesota Mining and Manufacturing Company. Whereas the GT-12 uses a relatively strong adhesive for bonding the scrim to the film, the 3M product apparently employs a thin polyethylene coating for this purpose. The complete coating makes the 3M composite a heat-sealable material, but fin seals in this material are probably much weaker than lap seals. GT-12 can be fabricated only with the latter geometry.

3. TESTING

3.1 Test Conditions

Tests were run using two conditions of environmental temperature: 25 ± 1^{o} C. and -79 ± 2^{o} C., respectively 73.4 ± 1.8^{o} F. and -110.2 ± 3.6^{o} F. Humidity at the testing machine was not controlled, and this environment normally varied from 20 to 50 percent during the term of the test program.

Prior to testing, the specimens of polyamide, polycarbonate, and polyurethane materials were kept in a humidity chamber at

50 ± 5 percent relative humidity at room temperature. These three polymers are known to absorb moisture from the atmosphere, and the mechanical effects of humidity change were observed in the polyamide films. Such effects were not observed in the other materials.

The low temperature tests were accomplished in a carbon dioxide environment. Cooling was accomplished with facility by injection of pressurized liquid carbon dioxide into the telescoping test chamber, where it flashed to solid upon expansion from a fine nozzle (made from a hypodermic needle). The solid CO_2 was directed upward from the nozzle and it then "snowed" down around the specimen under test. Temperatures were measured at three points near the center and extremities of the test specimen and these varied by less than 2° F. from the average chamber temperature. The outlet temperature was measured with an ASTM alcohol thermometer, and this temperature likewise varied from the average by less than 2° F. The equilibrium sublimation temperature for dry ice in Boulder is normally -80° C. or -112° F. This was the measured temperature in practically all of the tests, and is the reference temperature stated in the data and graphs which follow in this report.

3.2 Test Methods

A variety of plastic films, fabrics and elastomers were tested in this program, and ASTM procedures would normally recommend using different test methods for each type of material. However, since comparative results were the desired objective, one test method was used for all of the materials, to ascertain each of the desired mechanical properties.

Tensile strength was learned by ASTM D882-61T using samples 1" x 6" with 4-inch gage length. The cross-head rate was 0.5 inch per minute, providing a strain rate of 0.125 inch per inch per minute. The ultimate elongation was ascertained on this same test.

The tensile modulus data were obtained using the same ASTM specification, except for the recommended longer specimen and slower strain rate. A 10-inch gage length was used on a 1" x 12" specimen, and a cross-head rate of 1 inch per minute was specified. Autographic records of load vs. elongation were made during these tests, and corrections were made for the measured pendulum travel. These records were extended beyond the region of linear stress-strain behavior sufficiently so that a yield strength might be defined where appropriate.

The tear initiation tests were accomplished using ASTM D1004-61 (Graves tear test). A sharp die was used for cutting all of these specimens, and care was taken during installation of specimens in the grips. Cross-head speed was 2 inches/minute.

The tear propagation tests were non-standard and involved only a slight modification of the Graves procedure. A razor slit was made 1/16" deep into the notch of the Graves specimen, as shown in Figure 22. No changes were made in the mounting or cross-head rate of ASTM D1004. This test was a relatively simple way of obtaining tear propagation strengths at low temperatures.

The scrim-reinforced materials posed some special problems in tear testing, since failure involved a separation of the filament and the film, rather than rupture of the filament. The tear specimens were die-cut at random with no effort to locate the notch in a favorable or unfavorable position.

Since many of the balloon materials are intentionally or accidentally anisotropic in mechanical characteristics (properties are different in one direction from another direction), tests were made in orthogonal orientations--machine and transverse directions.

Thickness measurement of thin films can normally be made to a precision not better than 0.0001". In a 1-mil film, this is a ± 10 percent variation; in thinner films, it is a greater error. After starting on the program with thickness measurement and tensile strength calculation based upon the measured cross-section area, we concluded that greater accuracy and more meaningful results would be obtained from data expressed as strength per unit width and as weight per unit area. For this reason, the calculated strengths expressed in this report in psi units are based upon the nominal thickness only. The data expressing strength in pounds per inch width were obtained directly from the tests; and thicknesses expressed as weight per area were obtained from weights of the samples tested. Since the fabrics and scrim-film composites have no identifiable thickness, data for these materials are presented only on the basis of strength per width.

3.3 Analysis

Data were analyzed with an eye on statistics, even though only five replicate specimens were tested in most cases. The average value is presented, and the coefficient of deviation is reported for each condition. The latter term is the ratio of standard deviation to the average and indicates the relative scatter of the results. This scatter is due to one or more of the following causes:

a. material property variability
b. material thickness variation
c. testing machine error
d. technician performance variation

The first of these two variables have been combined into one measure by the practice of reporting strength per width; the latter two variables should preferably be negligible, but this can not be ascertained without a "round-robin" type of testing program. Where relative comparisons of materials are of importance, the latter two variables may be less significant than the former.

Where failure may occur by a variety of mechanisms, a large coefficient of deviation may be expected. The tear tests of film-scrim composites, for example were examples of such occurrence. For that matter, the Graves tear may propagate along any radius from the stress concentration; and by its seeking of the weakest path, a fair amount of variation may be anticipated.

4. MECHANICAL PROPERTIES

Data for all of the mechanical property tests are presented in Table 2. It may be noted that most of the materials were not homogeneous and isotropic, but that properties varied with direction and thickness.

4.1 Properties at 25° C.

4.1.1 Tensile Characteristics

The tensile stress-strain characteristics of the prospective balloon materials are presented in Figures 1 thru 8. The ultimate properties are presented in the first group of three graphs; properties in the modulus area, or low range of stress and strain are presented in the second of the three; and properties per weight are shown in the last two illustrations.

The tensile stress curves for the films are presented in Figure 1. These data relate to the machine direction only and follow most of the films through to their ultimate elongation. On this basis of equal areas, the films fall into relatively distinct groups: (1) materials with high elongation and relatively low early strength (polyethylenes, ethylene copolymer, and polyurethane); (2) materials with distinct elastic and plastic regions (polypropylene, polyamides and Lexan polycarbonate); and (3) high-strength materials with little elongation (oriented polypropylene and polyester films).

The same materials are described in Figure 2 where the thickness is non-weighted (strength presented in pounds per inch of material).

The fabric or scrim-reinforced materials can be described in terms only of strength per width (since there is no nominal thickness). These materials are compared in Figure 3 with Lexan, Mylar and oriented polypropylene films, carry-overs from Figure 2. The two nylon fabrics (Raven) are very close in stress-strain behavior to the Schjeldahl GT-12 polyester-dacron scrim. The 3-M polyester film-nylon scrim is of lower strength but slightly higher elongation. The ultimate strength for this material was taken at the point of film failure, which preceded breakage of the nylon filaments. Thus the 3-M scrim does not represent the best combination of materials for maximum balloon strength. Filament breakage was experienced in the three other materials of the composite group.

Since design parameters are based primarily upon the tensile properties up to and including the apparent yield point, the modulus curves are presented in Figures 4 thru 6. Figure 4 shows the low-modulus materials--polyethylene ethylene copolymer, slot cast polypropylene and polyurethane.

Additional films are presented in Figure 5; again the tensile stress is expressed in pounds per square inch. The elastic modulus of Mylar is here seen to exceed that of polyethylene by a factor of approximately 40. The approximate yield strength for each of the films is identified in each of these graphs. The yield point for each material was arbitrarily selected near the knee of the stress-strain curve. This was at a strain value for each material, as follows:

polyamide	.03
polyester	.03
polypropylene	.03
polycarbonate	.05
polyethylene	.08
polyurethane	.05

The fabrics and scrims are combined with the films to present tensile data in the same range in Figure 6, except that here the strength is expressed in pounds per inch width. None of these materials broke within the range presented on each curve; the loading was carried out only to such a point that a yield could be observed on the greatly expanded strain scale.

Properties are reduced to their areal density in Figures 7 and 8. The relationships between strength in the machine and transverse directions are also presented in these drawings. In general, the former direction was the stronger, but some materials were relatively isotropic and some showed a slight inversion of this characteristic. The materials with highest ultimate strength per unit weight were: oriented polypropylene, Raven 2A 1925, Schjeldahl GT-12, and Raven 2A2072. Polyester films by 3-M and by duPont were next, with transverse strength exceeding the machine direction strength in all three cases.

Where tensile yield strength was defined in Figures 4, 5 or 6, this value (converted to strength per width) is compared with weight per area in Figure 8. The highest ratios of yield strength per weight are found in the polyester films, oriented polypropylene and polycarbonate. The filament-reinforced films do not show true yield points (except for the 3-M scrim which broke the film before the filament) and they are not presented in Figure 8.

Actually the stress redistribution characteristics of the fabric-reinforced materials are superior to the plastic stress relieving properties of the films, and lack of yield point in the GT-12 and Raven materials is of no detriment. For these materials, the ultimate strength can be used as a basis for structural design (with adequate safety margin) rather than the yield strength.

4.1.2 Tear Characteristics

The data for tear initiation and tear propagation tests may be compared in Figure 9, which presents the cold tear characteristics as well as the 25° C. properties. The stress was applied in the machine direction in the tests of Figure 9. All materials showed lower tear propagation than tear initiation; Lexan, polyester films, and oriented polypropylene were most severely affected by the pre-cut stress concentration.

The force to propagate the stress in each material is related to areal density in Figure 10. The rip-stop nylon of the Raven materials is observed to perform as intended, and these show the highest resistance to tear propagation on a unit weight basis. GT-12, cast polypropylene and Capran polyamide films are next in sequence of tear propagation strength per weight. Lexan and oriented polypropylene were the weakest in tear strength per weight.

4.2 Properties at -80° C.

4.2.1 Tensile Characteristics

The transition from warm to cold environments accomplished a great "leveling" of stiffness characteristics among the materials. Two Consolidated polyethylene films stretched to over 175 percent elongation and the Visqueen polyethylene gave a 45 percent elongation. These were the only materials with more than 25 percent elongation at the low temperature. These data are shown in Figure 11 for the films; strengths per width for films and fabrics are shown in Figure 12.

Films exhibiting a yield and some ductility in terms of classical definitions were polyethylene, Lexan, and Texin. Polyester films, oriented polypropylene and the fabrics gave elongation values in the range of 10-25 percent. Although the ethylene copolymer exhibits a non-brittle failure at -80° C. (manufacturer's data) the elongation was only 8 percent in the samples tested.

Relations of ultimate strength at -80° C. to areal density are shown in Figure 13. As at room temperature, oriented polypropylene, polyester film and fabrics or scrims provide the best strength per weight.

The strength of most materials increased by 20 to 300 percent in the transition from room to cold temperature. The only exception was in the case of Raven 2A-1925 in the transverse direction; in this case the Mylar film ruptured at an elongation well below the ultimate strength capability of the nylon fabric.

The modulus and yield characteristic are presented in Figures 14-16. At -80° C. the elastic properties of oriented polypropylene and of the polyester films were nearly identical. The modulus of polyethylene was lowest of the group, at 2.7×10^5 psi and other materials ranged up to 8.7×10^5 psi. The polymer stiffness thus increases by factors of 1.5 to 60 in the transition from + 25 to -80° C. for these materials. Polycarbonate and polyester films appeared to be the least affected.

The modulus and yield properties of all materials are presented in Figure 15 with strength expressed in terms of pounds per inch width. On this basis, the Raven and Schjeldahl composites using Mylar films were slightly stiffer than the non-reinforced films at -80° C.

The yield strength at the cold temperature were again selected at arbitrary strain values as follows:

cast polypropylene	.01
polyurethane	.02
polyethylenes	.03
biax polypropylene	.03
polycarbonate	.04
polyester	.04

The tensile yield strengths of the films are presented for a weight comparison in Figure 16. As at room temperature, oriented polypropylene and polyester films are the best of the samples tested in this characteristic.

4.2.2 Tear Characteristic

The tear characteristics of the prospective materials were measured at low temperatures for perhaps the first time. Some of the materials gave a surprising tear behavior.

Tear propagation strength is the lesser magnitude of the two variables measured, and it is probably of greater significance. The force to propagate tears in the modified Graves specimens is shown for each material in Figure 17 as a function of areal density.

At the low temperature, the Raven fabrics, GT-12 and ethylene copolymer provided the highest tear propagation resistance per weight. Cast polypropylene, and the polyethylenes were next in sequence. Oriented polypropylene, polycarbonate and polyester films were the poorest of the materials in this characteristic.

There is a common temptation to assume that materials with high elongation capability will have good tear resistance. Additionally, the transition from 25 to -80° C. would usually be expected to decrease the tear strength of plastic films. Both of these considerations are incorrect generalities.

The tear propagation strengths and ultimate elongations of each material are shown for both temperatures in the bar graph of Figure 18. The relatively high tear strengths of the fabrics and scrims (3, 4, 9, 11) are accompanied by low filament elongations. These data do not contribute to the present argument but they do indicate the very real tear-stop advantages of filament reinforcements.

At room temperature, a slight correlation might be observed between higher tear strength and ultimate elongation. At -80° C. this correlation does not exist. In fact, among the 13 films tested at -80° C., 8 of the materials increased in tear propagation strength and 5 decreased in this property. Polyester films, Lexan and oriented polypropylene decreased in tear strength; the polyethylenes and cast polypropylene increased in tear propagation resistance.

At room temperature, the tear propagation strength of Mylar exceeded that of polyethylene; at -80° C. the reverse was true. At the low temperature, tear propagation strength per width was about 3 times greater than the tear strength of polyester films; this might be a clue to the relative success of non-reinforced balloons made from the two materials.

5. PHYSICAL PROPERTIES

Although several physical properties are of concern for the balloon films, only the radiation absorption characteristics were learned in this study. Spectroscopic transmission studies were made by a personal friend of the authors at the Martin Company, Denver.

5.1 Optical Transmission Characteristics

The films were tested in the range of 220 to 2800 millimicrons (2200 to 28,000 Angstroms), which covers ultraviolet through visible light. This is the principal range of solar radiation, and is significant as the source of radiant heating of balloons during daytime flight. These data do not describe the thermal emissive characteristics of the films.

The curves of Figures 19-21 present the percent transmission of radiant energy, in reference to the transmission by air. A portion of the incident light is reflected. Some is absorbed (leading to a temperature rise) and the remainder is transmitted. An estimate of absorptivity is best obtained where three or more thicknesses of a given material are tested. Such was not opportune in the present case. The data provide a relative comparison for estimating the daytime heating characteristics of the alternate balloon materials. Unity, minus the reflectance, minus the absorption equals the fraction of energy transmitted. Thus, a low transmission implies a high absorption, since the reflectance of plastic films is normally in the range of 5 to 10 percent.

The intensity of solar radiation is definitely a function of wavelength, as shown in Figure 19. A gross estimate of the solar heating may be obtained by integrating the product of solar intensity times the factor (1-transmission). This calculation would be excessively high, since it does not subtract the reflected energy; but it does provide an approximation for comparing different types of films.

Materials with high transmission in the 500 mu range were: polyethylene, polypropylene, polycarbonate (Lexan), polyamide (Capran), and polyester (Mylar). Polypropylene had the highest transmission among this group. Films of ethylene copolymer and of urethane (Texin) were highly absorptive in the principal solar wave lengths. In fact, the 2.5-mil Texin might as well be pigmented black. These two materials would experience high solar heating and would contribute to a large ballast requirement. Other films would not be very different from polyethylene in ballast requirements.

A sample of "smoked" polyethylene balloon film from India was included in the transmission tests; Mr. Karl Stefan of GMI (now Litton) provided this sample. Its optical transmission was virtually identical to that of 1.5-mil Visqueen. Thickness of the India sample was in the range of 1.4 to 1.7 mils. The transmission of the Visqueen sample, shown in Figure 29, is lower than expected (see the 2-mil Consolidated film); this leads to a query whether fingerprints or faulty technique might have influenced these results.

6. CONCLUSIONS

This test program has enlightened some opportunities for improvement of balloon material performance, and it has discounted the prospects for a number of alternative materials. The small number of replicate specimens has not provided design values for any of the materials. Conclusions are reviewed below in terms of each type of material.

6.1 Polyethylenes

The respectable tensile strength at room temperature and the excellent tear strength and elongation at low temperature are properties which will keep polyethylene as a strong contender for scientific balloons. But the question arises, which of the many polyethylenes is best? In this program, the Consolidated GF 19X film was superior to Visqueen A in low temperature elongation.

Perhaps other polymers and/or processing would provide still superior polyethylene film.

The average deviation coefficient among the ten strength properties were as follows:

Consolidated GF 19X	.001"	0.114
Visqueen A	.0015"	0.087
Consolidated GF 19X	.002"	0.079

These data reflect the difficulty of manufacturing uniform film in thinner gauges, as well as the greater probability of test errors in thinner films.

The superior elongation of polyethylene films at low temperature indicates that these materials are excellent prospects for film-scrim composites, if adequate bonds are obtainable between film and filament.

The rather low elongation of ethylene copolymer in Consolidated SF444 (#15 and 16) at -80° C. was a disappointment. This material has a lower brittle temperature than polyethylene, when tested by the impact method of ASTM D746. Since ultimate elongation or ductility is a design parameter of greater importance, the impact criterion becomes a little less significant for material selection or specification. The copolymer is not a satisfactory balloon film for non-reinforced fabrication. It might be satisfactory in combination with a scrim, for use to something like -60 or -70° C. Its low modulus would lead to fabrication difficulties, and day/night temperature variations would be greater than in Mylar or polyethylene balloons.

6.2 Polypropylene

Cast polypropylene film has higher tensile and tear strength than polyethylene at 25° C., but it has severe disadvantages at -80° C. Properties of biaxially oriented polypropylene are superior to the cast material at both temperatures, except for exceptionally low tear strength.

The 45° diagonal tensile strength of oriented polypropylene should be ascertained. If elongation in this direction is as good as the 23% observed in orthogonal directions at -80° C., this film would be excellent in scrim-reinforced balloons where film loads are avoided.

6.3 Polycarbonate

The "book values" of Lexan polycarbonate were not obtained in the film samples. Whereas molded samples usually give a 25° C. elongation of 85 to 105 percent, the films averaged only 25 percent elongation. Tear strength was also surprisingly low. The polycarbonate properties did not change significantly with temperature decrease.

These samples were taken from the first year's production of polycarbonate film, which is still made for electrical rather than mechanical applications. As there are improvements in mechanical properties in the future, polycarbonate film may become a stronger candidate for balloon construction.

6.4 Polyamide

After observation of the significant humidity effects on polyamide films, the Capran material was excluded from the test program. Dimensional changes as a result of moisture gain or loss would cause real problems in balloon fabrication. Moisture desorption during a flight could interfere with the information objectives of the payload instruments. Nylon films are not appropriate for scientific balloons.

6.5 Polyester

The polyester films of duPont and 3M are very respectable in their properties at 25° C. and at -80° C. Limited tear strength and elongation at the low temperature are the major disadvantages. The properties of duPont Mylar and 3M polyester film were virtually equivalent; the Mylar was more nearly isotropic. The 3M film was best in its transverse direction, and a slight orientation in the machine direction might be of advantage for this material.

The average deviation coefficients for the 20 strength tests were as follows:

Mylar	.0005"	0.14
Mylar	.001"	0.11
3M	.001"	0.13

These numbers are comparable to those for polyethylene of similar thickness. This indicates that testing variance plus the material variability for polyester is similar to the polyethylene counterparts.

The limited elongation of the polyester films at -80° C. (8.7 percent average in the 0.5-mil film) is a disadvantage even in scrim-reinforced composites. Where diagonal shear stresses are involved, the film strain of GT-12 can be as much as 31.6 percent before the filaments take over the stresses. This concern should be substantiated by measurement of the diagonal elongation, rather than a mere average of machine and transverse elongations as was done to obtain the 8.7 percent figure.

6.6 Polyurethane

Like Lexan, the polyurethane film was a very young product whose properties will likely improve with further production maturity. The sample was laboratory extruded and a large number of pin-holes and other defects were visible in the 2.5-mil film. The thermoplastic Texin behaved as an elastomer, with a typical sigmoidal (S-shaped) stress-strain curve. The high tensile strength was not developed until large strains were obtained, thus the material would not be appropriate as the structural member of a natural shape balloon. The Texin film might have prospects for meteorological balloons in the future.

6.7 Composites

The advantage of composite film-filament materials were apparent from the results of this test program. Both the closely knitted rip-stop parachute fabric and the woven scrims provided exceptionally high strength and tear resistance. Both types of fabrication were able to redistribute stress concentrations efficiently.

The Raven 2A-1925 laminate of Mylar with nylon parachute fabric and the Schjeldahl GT-12 were virtually equivalent in mechanical characteristics at both temperatures and in weight per area. Further tests at a diagonal angle, or shear or biaxial tests, might show a difference between these materials in diagonal elongation requirements.

The 3-M composite of polyester film with nylon fabric (and apparently a polyethylene interlayer) was not as good as GT-12, particularly because of limited film elongation.

The excellent mechanical properties of the Raven composite suggest that another good material might be available at about 80 percent of its weight per area. This alternate would use light-weight flare cloth with a film of polyester, polyethylene or polypropylene.

Equally good or better composites can probably be made using non-woven filaments in preferred geometric patterns to provide high strength reinforcement to thin barrier films.

TABLE 1

Sources and Characteristics of Materials

No.	Type	Source	Density	Melt Index
1.	Polyamide Film .001"	Capran* Allied Chemical Company	1.15	
2.	Polyamide Film .002"	Capran* Allied Chemical Company	1.15	
3.	Polyamide Fabric with Acryloid Coating	Raven Industries #2A-2072		
4.	Polyamide Fabric with Polyester Film	Raven Industries #2A-1925		
5.	Polycarbonate Film .001"	Lexan* General Electric Company, Plastics Department	1.20	
6.	Polycarbonate Film .002"	Lexan* General Electric	1.20	
7.	Polyester Film .0005"	Mylar C* by duPont obtained from Schjeldahl	1.395	
8.	Polyester Film .001"	Mylar C* by duPont obtained from Schjeldahl	1.395	
9.	Polyester-Dacron* Scrim	GT-12, Schjeldahl		
10.	Polyester Film .001"	Minnesota Mining & Manufacturing Company, No. G10		

* Indicates Trademark.

TABLE 1 (Continued)

Sources and Characteristics of Materials

No.	Type	Source	Density	Melt Index
11.	Polyester-Nylon	SLP 50441, MMM Company		
12.	Polyethylene Film .001"	Consolidated Thermoplastics GF 19X	.922	0.6
13.	Polyethylene Film .002"	Consolidated GF 19X	.922	0.6
14.	Polyethylene Film .0015"	Visqueen* A		
15.	Polyethylene Copolymer .001"	Consolidated Thermoplastics SF 444	.932	2.0
16.	Polyethylene Copolymer .002"	Consolidated SF 444	.932	2.0
17.	Polypropylene Film .001" Slot Cast	Udel* Union Carbide Plastics Company	.895	
18.	Polypropylene Film .0005" Biaxial Orientation	Udel* Union Carbide Plastics Company	.902	
19.	Polyurethane Film .0025"	Texin 192A* Mobay Chemical Company	.0025	

*Indicates Trademark.

Table II-A TEST RESULTS AT 25°C.

Material Number	Film Type, Name	Direction[x]	Film Thickness (Inches)	Weight Per 1000 Square Feet (Pounds)	Ultimate Tensile Strength		Tensile Yield Strength		Elongation At Yield No Deviation (Percent)	Ultimate Elongation		Tensile Modulus		Tear Initiation		Tear Propagation		M or T	#
					Average (P.S.I.)	Deviation Coefficient	Average (P.S.I.)	Deviation Coefficient		Average (Percent)	Deviation Coefficient	Average (P.S.I.)	Deviation Coefficient	Average (Pounds per Inch)	Deviation Coefficient	Average (Pounds per Inch)	Deviation Coefficient		
1	Polyamide Film	M	.001	6.2	7910	.078	2500	.060	3	250	.053	98900	.045	1020	.049	840	.055	M	1
	Allied Capran	T			6150	.013	2600	.069	3	233	.120	105000	.140	1020	.097	690	.100	T	
2	Polyamide Film	M	.002	11.5	7690	.020	4720	.380	3	290	.043	260000	.380	1210	.110	850	.074	M	2
	Allied Capran	T			7700	.080	3810	.110	3	285	.085	268000	.140	1260	.120	820	.040	T	
3	Polyamide Fabric - Acryloid	M	--	13.3	42.1*	.055	--	--	--	25	.085	244*	.079	3.14⊕	.044	3.09⊕	.092	M	3
	Coating Raven 2A-2072	T			35.6*	.130	--	--	--	30	.033	73*	.020	2.95⊕	.038	2.93⊕	.100	T	
4	Polyamide Fabric - Polyester	M	--	10.2	43.6*	.039	--	--	--	24	.051	388*	.037	4.46⊕	.093	3.73⊕	.095	M	4
	Laminate Raven 2A-1925	T			29.8*	.093	--	--	--	30	.130	243*	.037	4.56⊕	.120	3.87⊕	.090	T	
5	Polycarbonate Film	M	.001	6.3	8340	.053	7880	.077	5	10	.410	119000	.240	770	.340	250	.094	M	5
	Lexan	T			8340	.014	7560	.017	5	14	.480	239000	.110	690	.370	260	.030	T	
6	Polycarbonate Film	M	.002	12.1	8560	.020	7835	.018	5	50	.360	230000	.030	733	.160	244	.100	M	6
	Lexan	T			8520	.035	7675	.029	5	27	.620	238000	.059	564	.220	179	.120	T	
7	Polyester Film	M	.0005	3.7	16800	.098	12540	.049	3	57	.190	593000	.018	1480	.220	630	.120	M	7
	Mylar	T			19900	.060	12540	.013	3	38	.130	708000	.018	1410	.300	670	.030	T	
8	Polyester Film	M	.001	7.2	18100	.029	13900	.052	3	41	.110	588000	.063	1530	.087	610	.020	M	8
	Mylar	T			21100	.097	13300	.035	3	84	.270	516000	.078	1240	.25	510	.100	T	
9	Polyester Scrim	M	--	10.5	44.6*	.022	--	--	--	22	.120	494*	.038	3.33⊕	.26	1.93⊕	.380	M	9
	Schjeldahl GT-12	T			33.2*	.036	--	--	--	21	.048	482*	.066	2.23⊕	.40	1.62⊕	.089	T	
10	Polyester Film	M	.001	6.6	17700	.090	11470	.049	3	42	.410	441000	.046	1170	.14	700	.250	M	10
	3M	T			25500	.170	11700	.031	3	31	.410	567000	.026	770	.13	580	.096	T	
11	Polyester Scrim	M	--	11.3	17.0*	.120	--	--	--	23	.320	200*	.056	1.09⊕	.31	.66⊕	.230	M	11
	3M SLP50441	T			16.7*	.100	--	--	--	32	.450	231*	.095	1.17⊕	.11	.78⊕	.190	T	
12	Polyethylene Film	M	.001	4.8	2140	.016	1020	.094	8	200	.300	15200	.040	590	.048	510	.049	M	12
	Consolidated GF19X	T			1330	.100	1000	.059	8	236	.320	17200	.077	510	.087	360	.110	T	
13	Polyethylene Film	M	.002	9.9	2080	.150	1000	.052	8	387	.160	17300	.087	543	.069	450	.011	M	13
	Consolidated GF19X	T			2020	.073	996	.005	8	438	.058	17800	.087	493	.032	400	.051	T	
14	Polyethylene Film	M	.0015	7.4	3970	.170	850	.040	8	456	.170	14400	.035	581	.036	416	.018	M	14
	Vis-Queen A	T			3510	.180	800	.027	8	442	.110	13500	.130	440	.037	388	.036	T	
15	Polyethylene-Polyacrylate	M	.001	5.3	1440	.130	515	.130	8	219	.230	6000	.170	390	.099	290	.110	M	15
	Consolidated SF444	T			1410	.079	460	.140	8	402	.052	5480	.098	430	.054	200	.130	T	
16	Polyethylene-Polyacrylate	M	.002	9.9	2010	.042	398	.095	8	443	.021	4810	.110	360	.062	260	.043	M	16
	Consolidated SF444	T			1470	.093	410	.081	8	455	.017	5500	.062	360	.031	210	.053	T	
17	Polypropylene Film	M	.001	4.3	5030	.130	2080	.049	3	520	.150	110000	.120	890	.069	670	.064	M	17
	Udel Slot Cast	T			2750	.250	1980	.130	3	520	.260	106000	.170	660	.260	390	.120	T	
18	Polypropylene Film	M	.0005	2.6	20800	.191	5040	.083	3	36	.220	308000	.100	1060	.143	96	.628	M	18
	Udel Biaxial Oriented	T			21700	.153	6030	.015	3	38	.254	346000	.141	1000	.292	120	.312	T	
19	Polyurethane Film	M	.0025	15.7	5510	.264	1040	.104	50	343	.283	3670	.156	670	.160	370	.030	M	19
	Mobay Texin	T			4310	.709	790	.107	50	423	.149	4360	.083	640	.041	280	.138	T	

x: M - Force applied parallel to the machine direction of the film.
T - Force applied in the transverse direction, perpendicular to the machine direction.

* Units, Pounds per Inch Width

⊕ Units, Pounds

Table II-B TEST RESULTS AT -80°C.

Material Number	Film Type, Name	Direction^x	Film Thickness (Inches)	Weight Per 1000 Square Feet (Pounds)	Ultimate Tensile Strength Average (P.S.I.)	Ultimate Tensile Strength Deviation Coefficient	Tensile Yield Strength Average (P.S I.)	Tensile Yield Strength Deviation Coefficient	Elongation At Yield No Deviation (Percent)	Ultimate Elongation Average (Percent)	Ultimate Elongation Deviation Coefficient	Tensile Modulus Average (10^3 P.S.I.)	Tensile Modulus Deviation Coefficient	Tear Initiation Average (Pounds per Inch)	Tear Initiation Deviation Coefficient	Tear Propagation Average (Pounds per Inch)	Tear Propagation Deviation Coefficient	M or T	#
3	Polyamide Fabric - Acryloid Coating Raven 2A-2072	M	--	13.3	49.0*	.190	--	--	--	15.7	.110	589*	.150	5.2⊕	.110	4.3⊕	.100	M	3
		T			42.2*	.120	--	--	--	22.4	.090	380*	.130	5.2⊕	.023	4.7⊕	.100	T	
4	Polyamide Fabric - Polyester Laminate Raven 2A-1925	M	--	10.2	56.2*	.080	--	--	--	12.3	.150	964*	.087	4.7⊕	.170	5.5⊕	.120	M	4
		T			21.0*	.280	--	--	--	5.6	.150	684*	.055	6.9⊕	.210	6.6⊕	.180	T	
5	Polycarbonate Film Lexan	M	.001	6.3	12640	.046	10280	.075	4	7.9	.120	330	.120	670	.500	132	.290	M	5
		T			11680	.080	9820	.085	4	7.7	.140	287	.270	774	.250	54	.210	T	
6	Polycarbonate Film Lexan	M	.002	12.1	14780	.120	10220	.058	4	16.3	.560	355	.190	736	.240	246	.100	M	6
		T			13860	.087	10530	.036	.4	9.5	.074	360	.089	680	.380	234	.065	T	
7	Polyester Film Mylar	M	.0005	3.7	24000	.030	20620	.032	4	11.1	.200	789	.090	1290	.055	396	.330	M	7
		T			22500	.120	23640	.071	4	6.3	.230	892	.084	1610	.280	212	.780	T	
8	Polyester Film Mylar	M	.001	7.2	27700	.037	23160	.031	4	15.1	.440	790	.044	1720	.039	390	.460	M	8
		T			30400	.100	21920	.058	4	45.4	.620	749	.062	970	.040	190	.540	T	
9	Polyester Scrim Schjeldahl GT-12	M	--	10.5	57.1*	.120	--	--	--	12.9	.048	920*	.076	3.4⊕	.330	3.4⊕	.340	M	9
		T			36.1*	.064	--	--	--	9.0	.130	511*	.036	3.4⊕	.270	2.2⊕	.510	T	
10	Polyester Film 3M	M	.001	6.6	26700	.065	21940	.062	4	10.7	.250	731	.059	1470	.044	230	.500	M	10
		T			34300	.096	22460	.036	4	12.0	.330	844	.047	1230	.240	350	.300	T	
11	Polyester Scrim 3M SLP50441	M	--	11.3	18.2*	.058	--	--	--	4.3	.110	616*	.120	1.0⊕	.480	1.1⊕	.270	M	11
		T			17.6*	.043	--	--	--	3.6	.180	77*	.052	1.3⊕	.160	0.7⊕	.190	T	
12	Polyethylene Film Consolidated GF19X	M	.001	4.8	10300	.200	5420	.155	3	206.0	.120	339	.130	1400	.064	1080	.100	M	12
		T			7500	.024	5470	.127	3	22.2	.530	468	.095	970	.035	750	.130	T	
13	Polyethylene Film Consolidated GF19X	M	.002	9.9	8560	.072	5420	.023	3	187.0	.420	276	.038	1210	.100	950	.088	M	13
		T			8160	.066	5700	.108	3	104.0	.370	299	.200	1120	.120	760	.029	T	
14	Polyethylene Film Vis-Queen A	M	.0015	7.4	8490	.026	5690	.125	3	45.5	.500	373	.110	1190	.140	740	.170	M	14
		T			7540	.084	6500	.081	3	7.3	.420	403	.076	1040	.091	710	.098	T	
15	Polyethylene-Polyacrylate Consolidated SF444	M	.001	5.3	7520	.110	6520	.040	3	7.5	.051	377	.180	970	.017	710	.130	M	15
		T			7430	.046	6380	.087	3	8.0	.190	363	.079	730	.180	550	.130	T	
16	Polyethylene-Polyacrylate Consolidated SF444	M	.002	9.9	7360	.092	6260	.203	3	8.7	.380	280	.100	870	.160	650	.120	M	16
		T			5710	.130	6060	.018	3	9.4	.350	430	.075	840	.170	490	.069	T	
17	Polypropylene Film Udel Slot Cast	M	.001	4.3	8710	.083	5260	.074	1	4.5	.320	497	.066	970	.180	890	.080	M	17
		T			6050	.065	4820	.157	1	7.3	.600	412	.140	1100	.065	840	.150	T	
18	Polypropylene Film Udel Biaxial Oriented	M	.0005	2.6	31600	.089	18000	.070	3	23.8	.390	878	.066	1360	.340	70	.390	M	18
		T			25800	.250	19800	.029	3	23.7	.780	1024	.074	1610	.240	100	.480	T	
19	Polyurethane Film Mobay Texin	M	.0025	15.7	8600	.173	6400	.123	2	11.2	.774	408	.049	1410	.218	1080	.186	M	19
		T			7560	.230	6720	.120	2	6.3	.780	374	.126	1360	.141	990	.096	T	

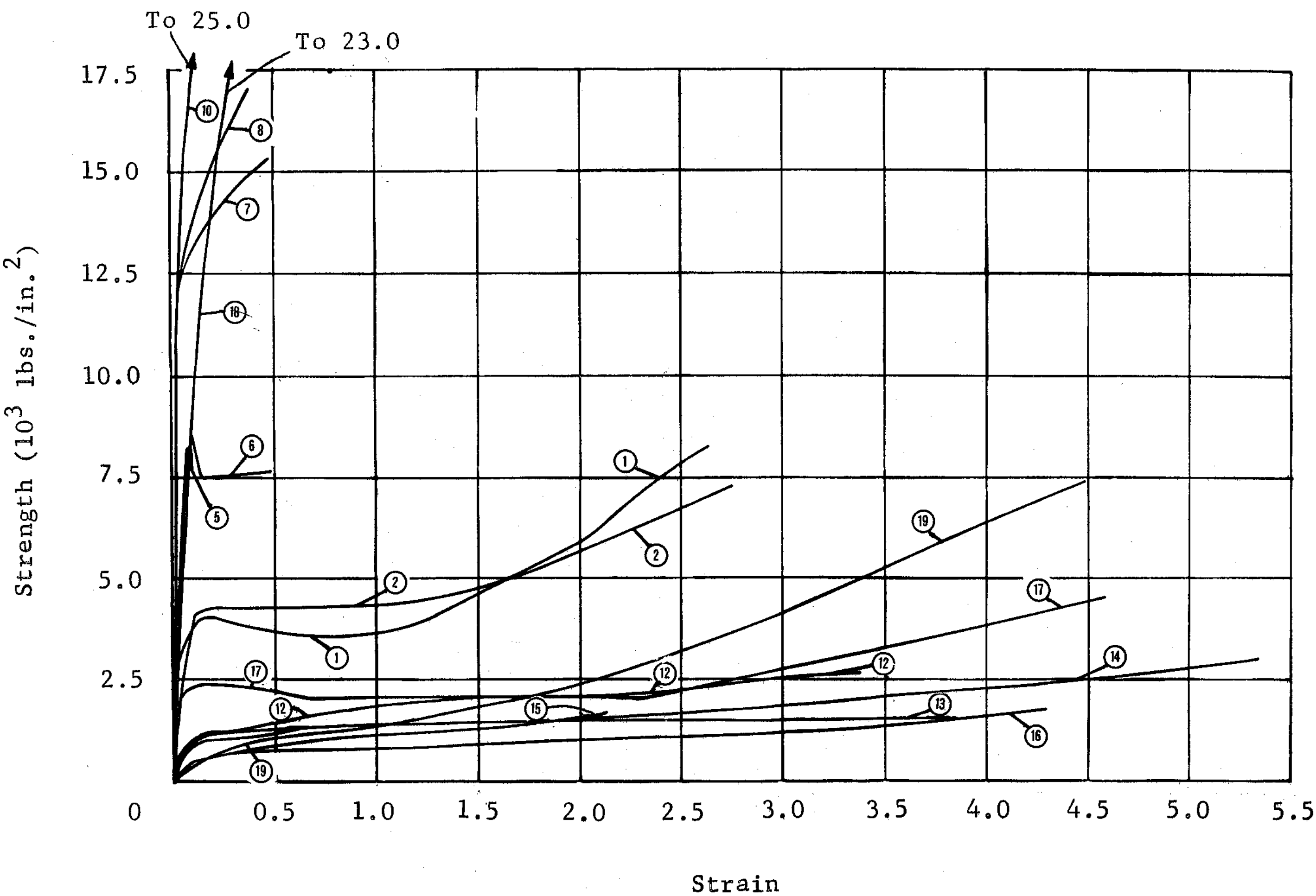
x: M - Force applied parallel to the machine direction of the film.
T - Force applied in the transverse direction, perpendicular to the machine direction.

* Units, Pounds per Inch Width

⊕ Units, Pounds

Figure 1 TYPICAL TENSILE CURVES, +25° C.

Machine Direction

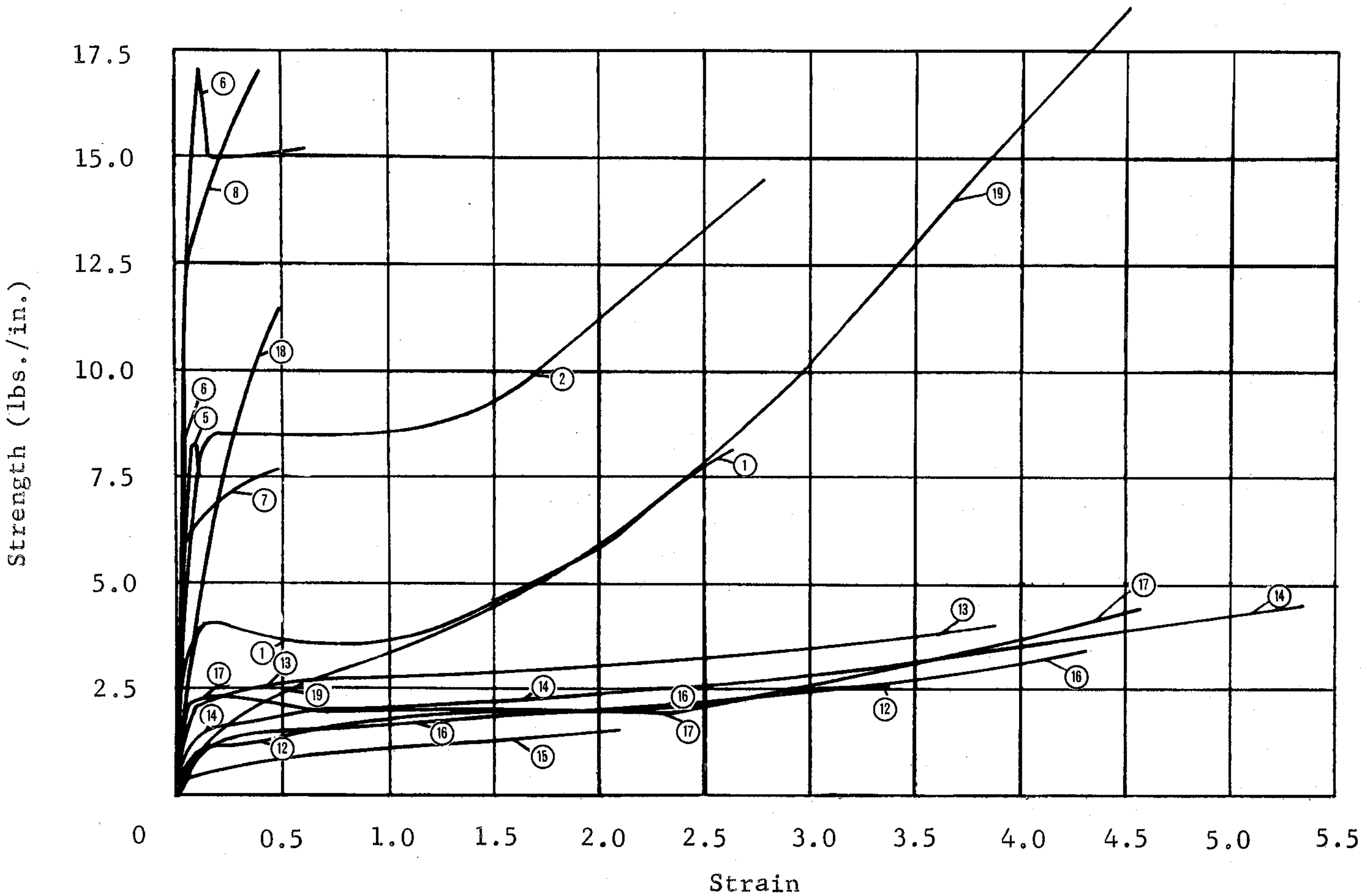


Key:

Code	Film	Thk, mils
1	Allied Capran	1.0
2	Allied Capran	2.0
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
10	3M Polyester	1.0
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 2 TYPICAL TENSILE CURVES, +25° C.

Machine Direction

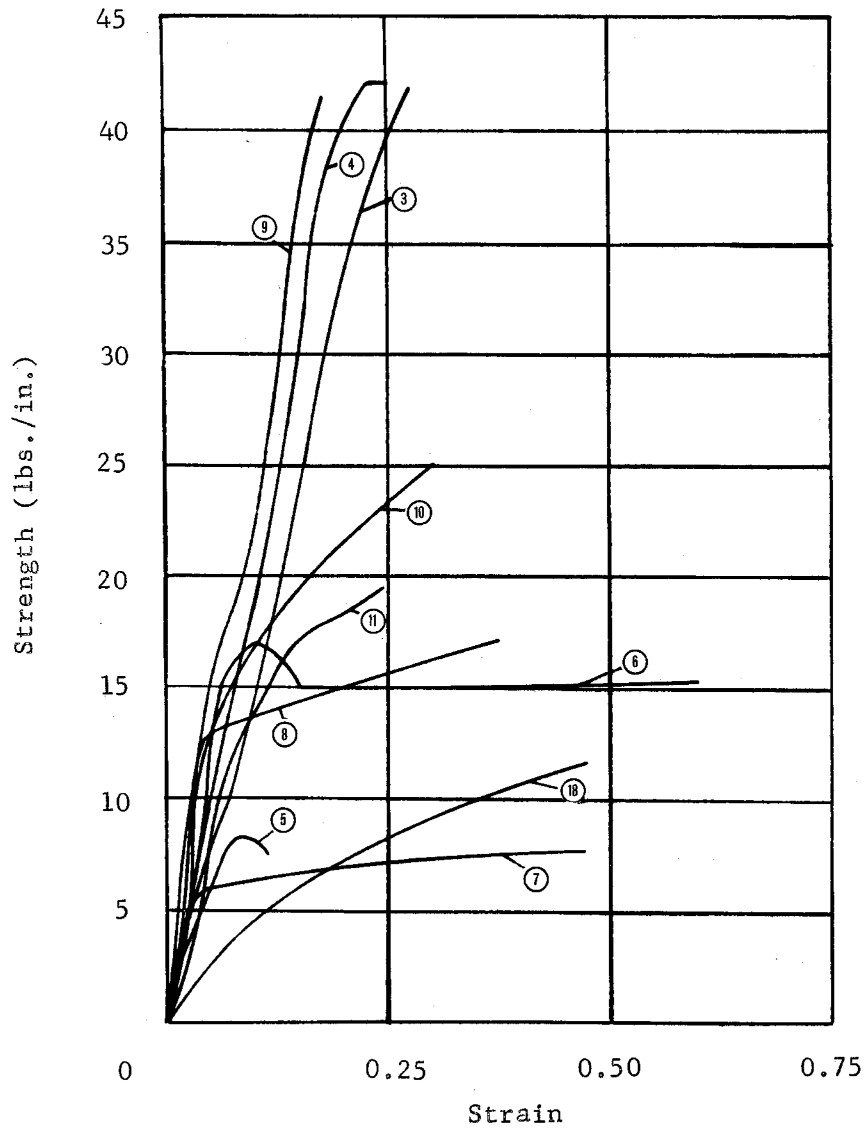


Key:

Code	Film	Thk, mils
1	Allied Capran	1.0
2	Allied Capran	2.0
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 3 TYPICAL TENSILE CURVES, +25° C.

Machine Direction

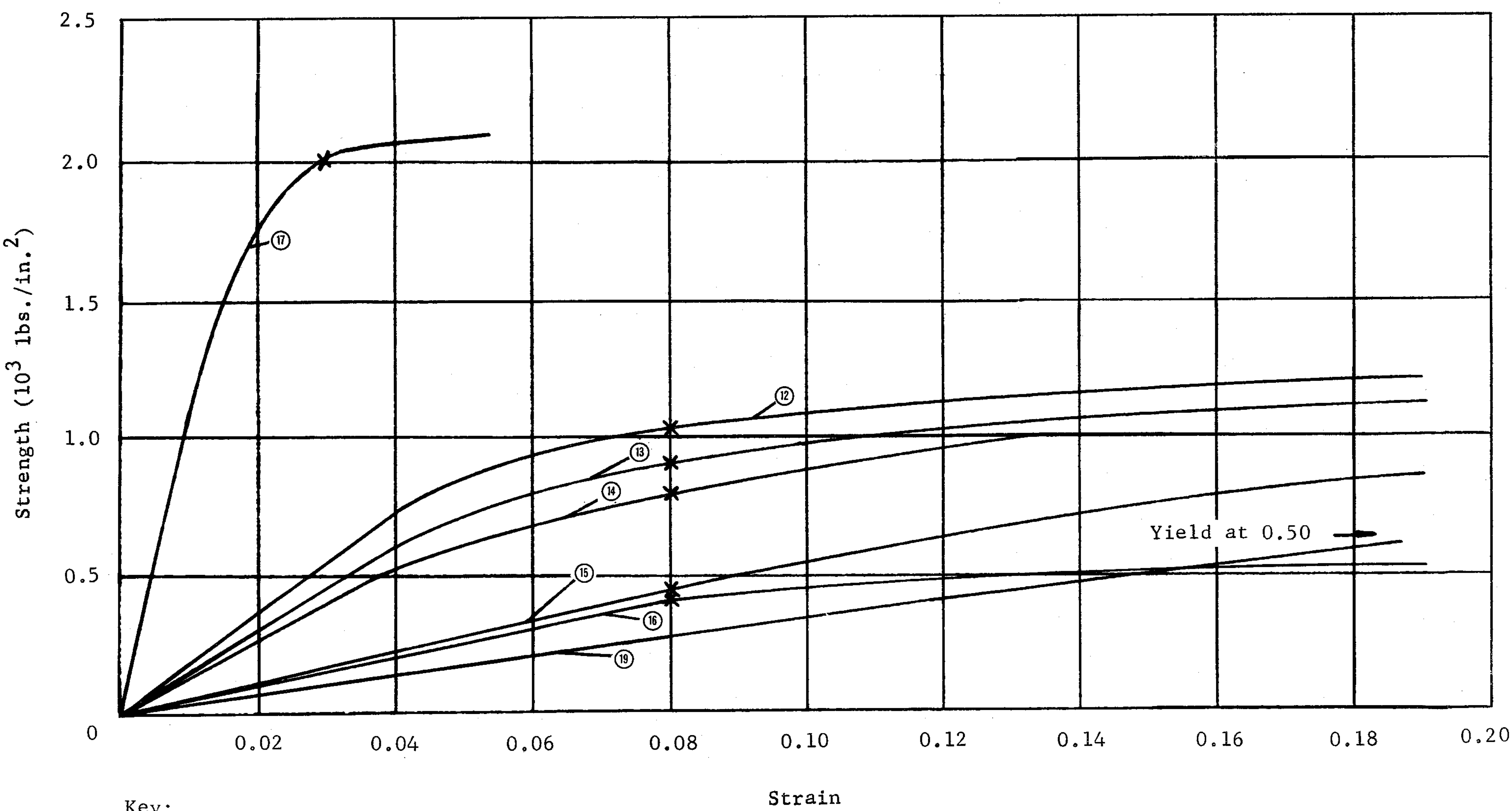


Key:

Code	Film	Thk, mils
3	Raven 2A-2072	-
4	Raven 2A-1925	-
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
9	Schjeldahl GT-12	-
10	3M Polyester	1.0
11	3M Scrim	-
18	Biax Polypropylene	0.5

Figure 4 TYPICAL MODULUS CURVES, +25° C.

Machine Direction



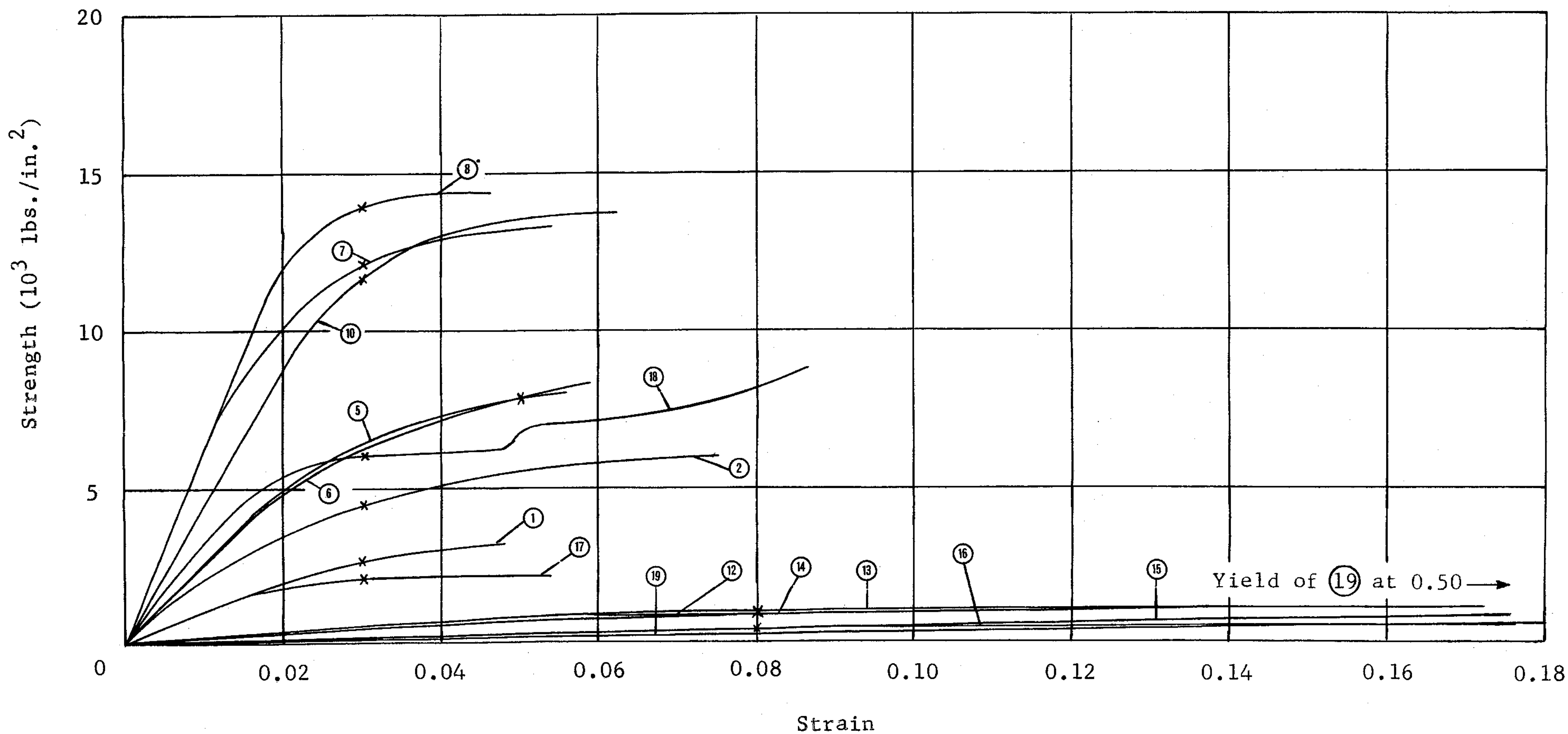
Key:

x = Yield Point

Code	Film	Thk, mils	Code	Film	Thk, mils
12	Consolidated GF19X	1.0	16	Consolidated SF444	2.0
13	Consolidated GF19X	2.0	17	Cast Polypropylene	1.0
14	Vis-Queen A	1.5	19	Mobay Texin	2.5
15	Consolidated SF444	1.0			

Figure 5 TYPICAL MODULUS CURVES, +25° C.

Machine Direction



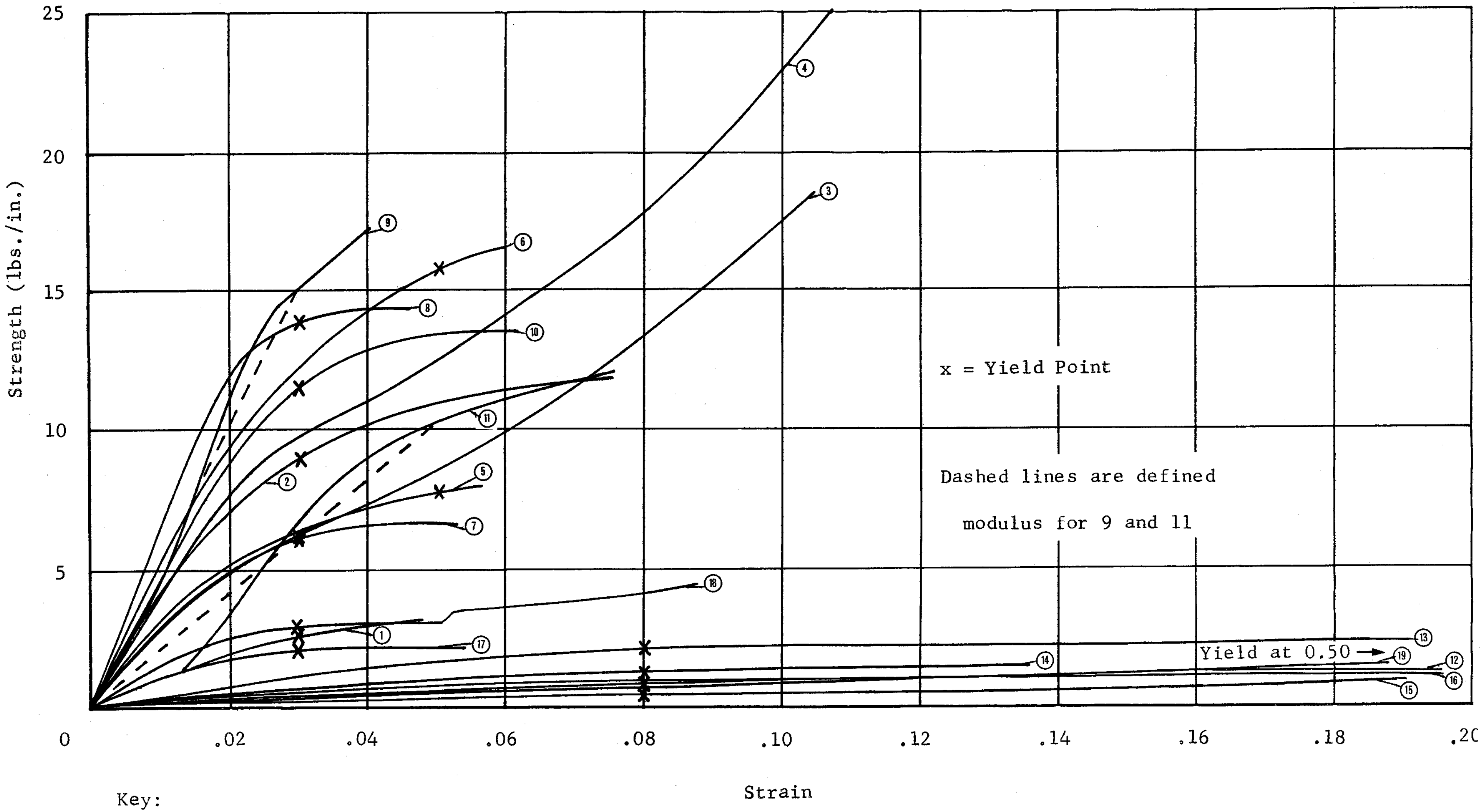
x = Yield Point

Key:

Code	Film	Thk, mils
1	Allied Capran	1.0
2	Allied Capran	2.0
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
10	3M Polyester	1.0
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 6 TENSILE MODULUS CURVES, +25° C.

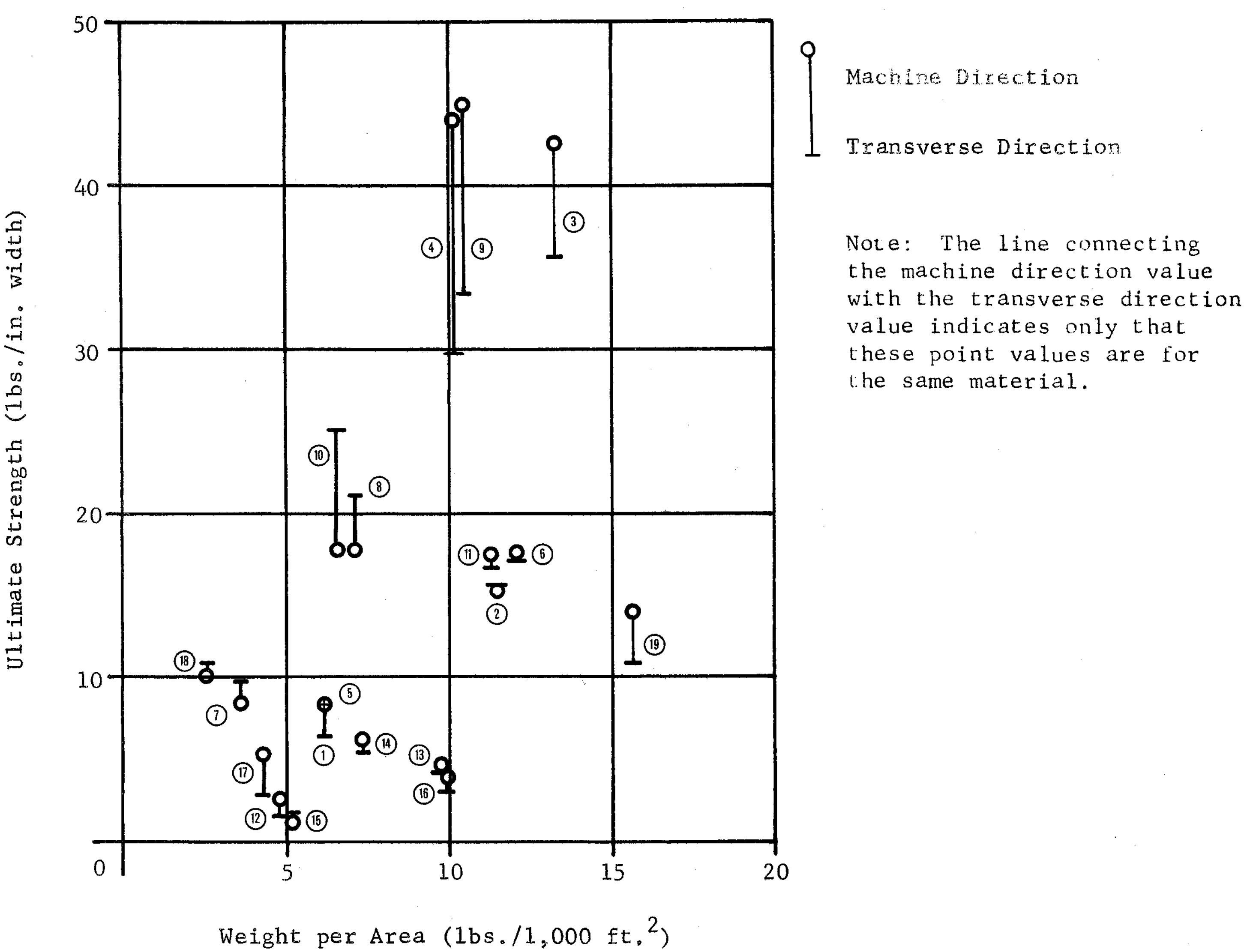
Machine Direction



Key:

Code	Film	Thk, mils	Code	Film	Thk, mils	Code	Film	Thk, mils
1	Allied Capran	1.0	8	Mylar	1.0	14	Vis-Queen A	1.5
2	Allied Capran	2.0	9	Schjeldahl GT-12	-	15	Consolidated SF444	1.0
3	Raven 2A-2072	-	10	3M Polyester	1.0	16	Consolidated SF444	2.0
4	Raven 2A-1925	-	11	3M Scrim	-	17	Cast Polypropylene	1.0
5	Lexan	1.0	12	Consolidated GF19X	1.0	18	Biax Polypropylene	0.5
6	Lexan	2.0	13	Consolidated GF19X	2.0	19	Mobay Texin	2.5
7	Mylar	0.5						

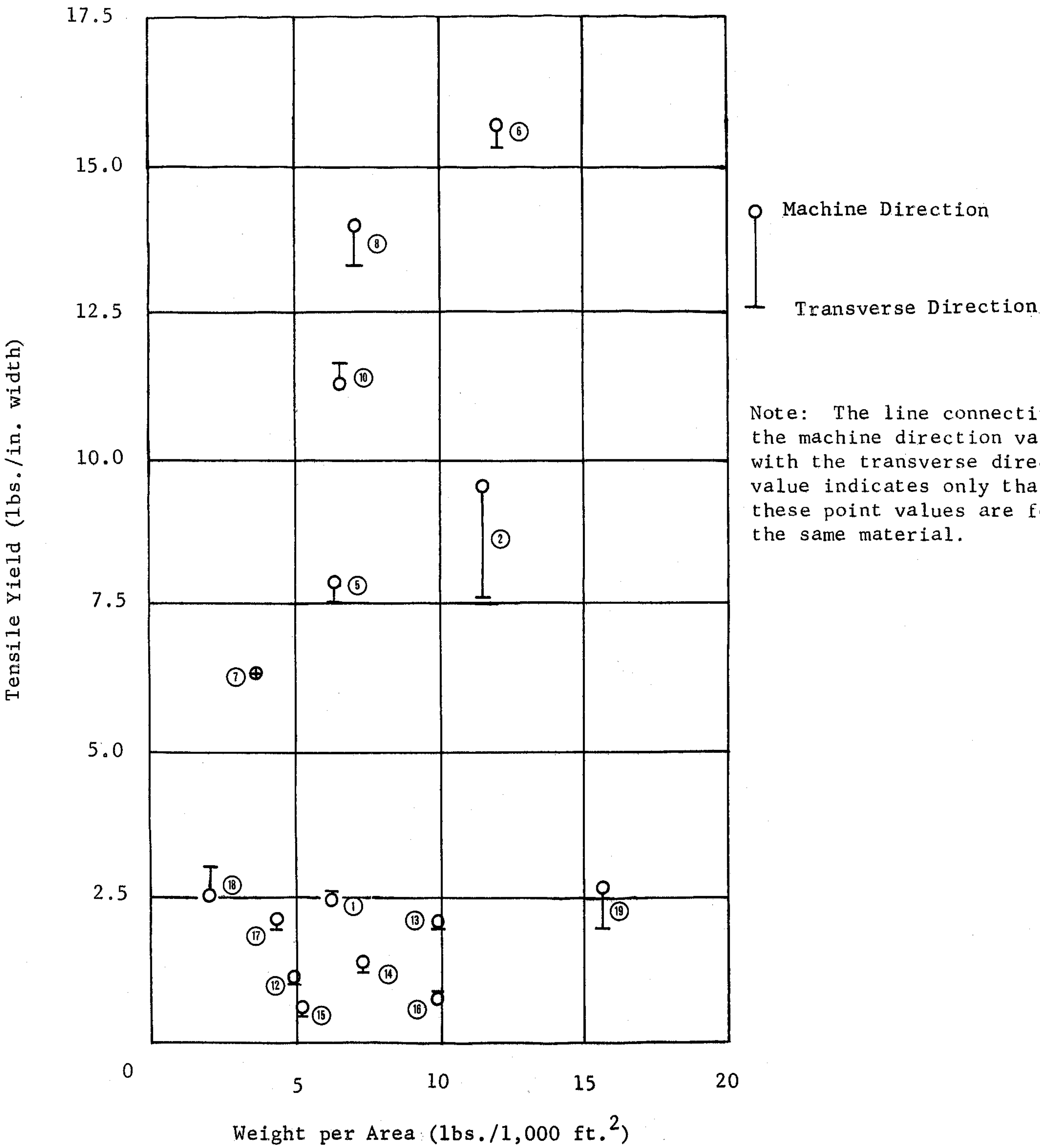
Figure 7 STRENGTH VERSUS WEIGHT PER AREA AT + 25° C.



Key:

Code	Film	Thk, mils
1	Allied Capran	1.0
2	Allied Capran	2.0
3	Raven 2A-2072	-
4	Raven 2A-1925	-
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
9	Schjeldahl GT-12	-
10	3M Polyester	1.0
11	3M Scrim	-
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 8 TENSILE YIELD VERSUS WEIGHT PER AREA AT + 25° C.

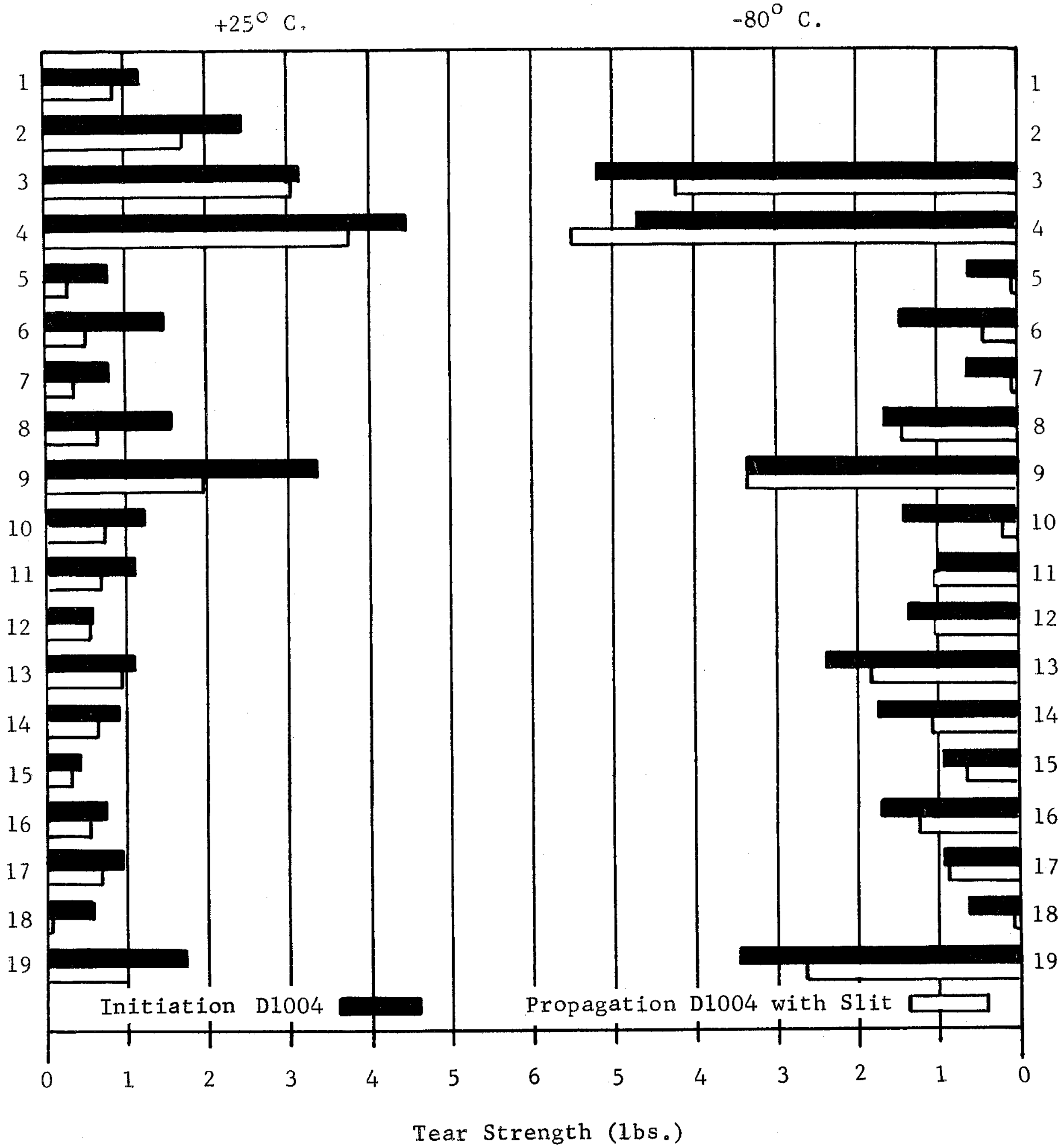


Note: The line connecting the machine direction value with the transverse direction value indicates only that these point values are for the same material.

Key:

Code	Film	Thk, mils
1	Allied Capran	1.0
2	Allied Capran	2.0
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
10	3M Polyester	1.0
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

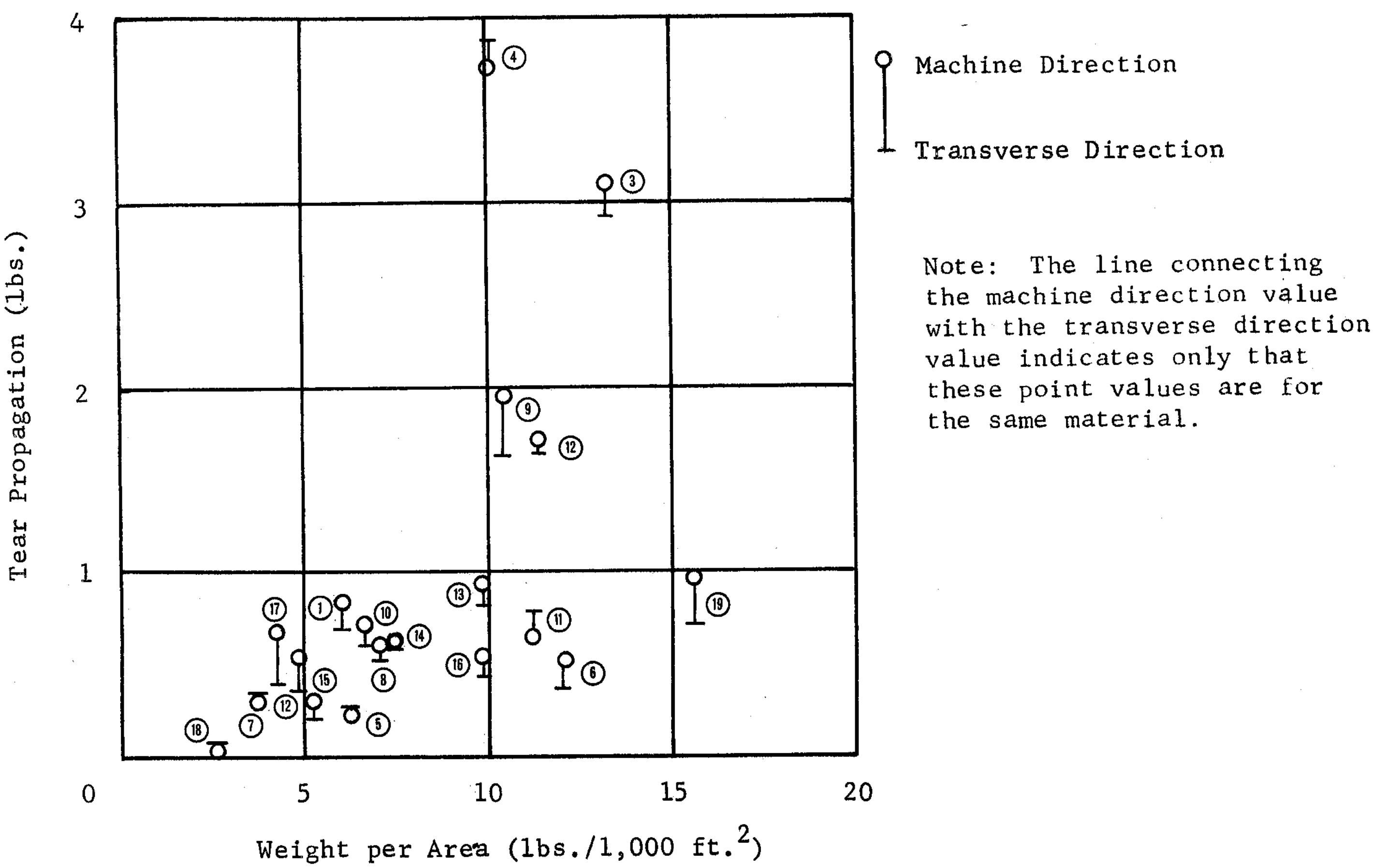
Figure 9 TEAR INITIATION AND PROPAGATION VALUES FOR MACHINE DIRECTION AT + 25° C. AND -80° C.



Key:

Code	Film	Thk, mils	Code	Film	Thk, mils
			10	3M Polyester	1.0
			11	3M Scrim	-
1	Allied Capran	1.0	12	Consolidated GF19X	1.0
2	Allied Capran	2.0	13	Consolidated GF19X	2.0
3	Raven 2A-2072	-	14	Vis-Queen A	1.5
4	Raven 2A-1925	-	15	Consolidated SF444	1.0
5	Lexan	1.0	16	Consolidated SF444	2.0
6	Lexan	2.0	17	Cast Polypropylene	1.0
7	Mylar	0.5	18	Biax Polypropylene	0.5
8	Mylar	1.0	19	Mobay Texin	2.5
9	Schjeldahl GT-12	-			

Figure 10 TEAR PROPAGATION VERSUS WEIGHT PER AREA AT + 25° C.

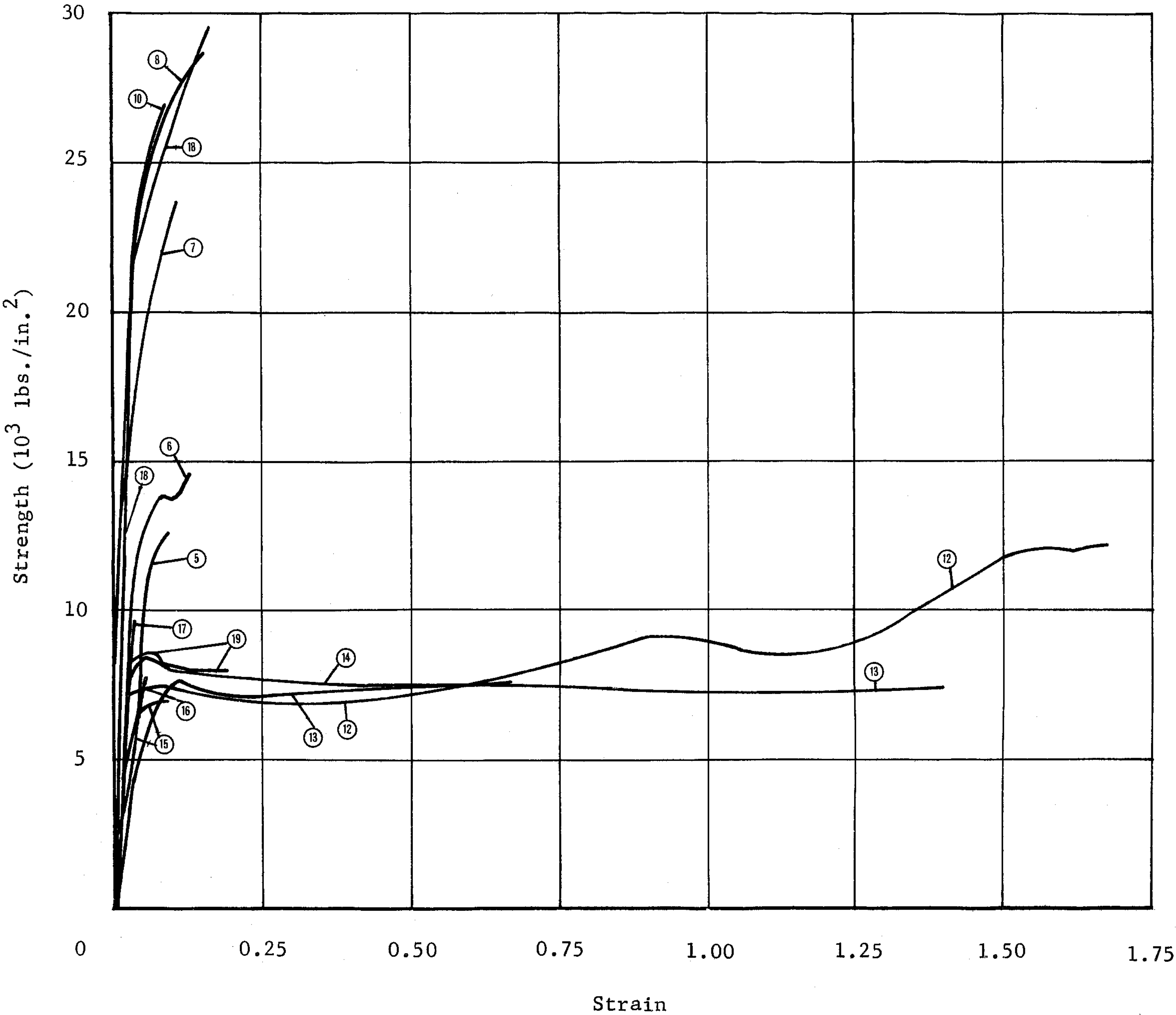


Key:

Code	Film	Thk, mils
1	Allied Capran	1.0
2	Allied Capran	2.0
3	Raven 2A-2072	-
4	Raven 2A-1925	-
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
9	Schjeldahl GT-12	-
10	3M Polyester	1.0
11	3M Scrim	-
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 11 TYPICAL TENSILE CURVES, -80° C.

Machine Direction

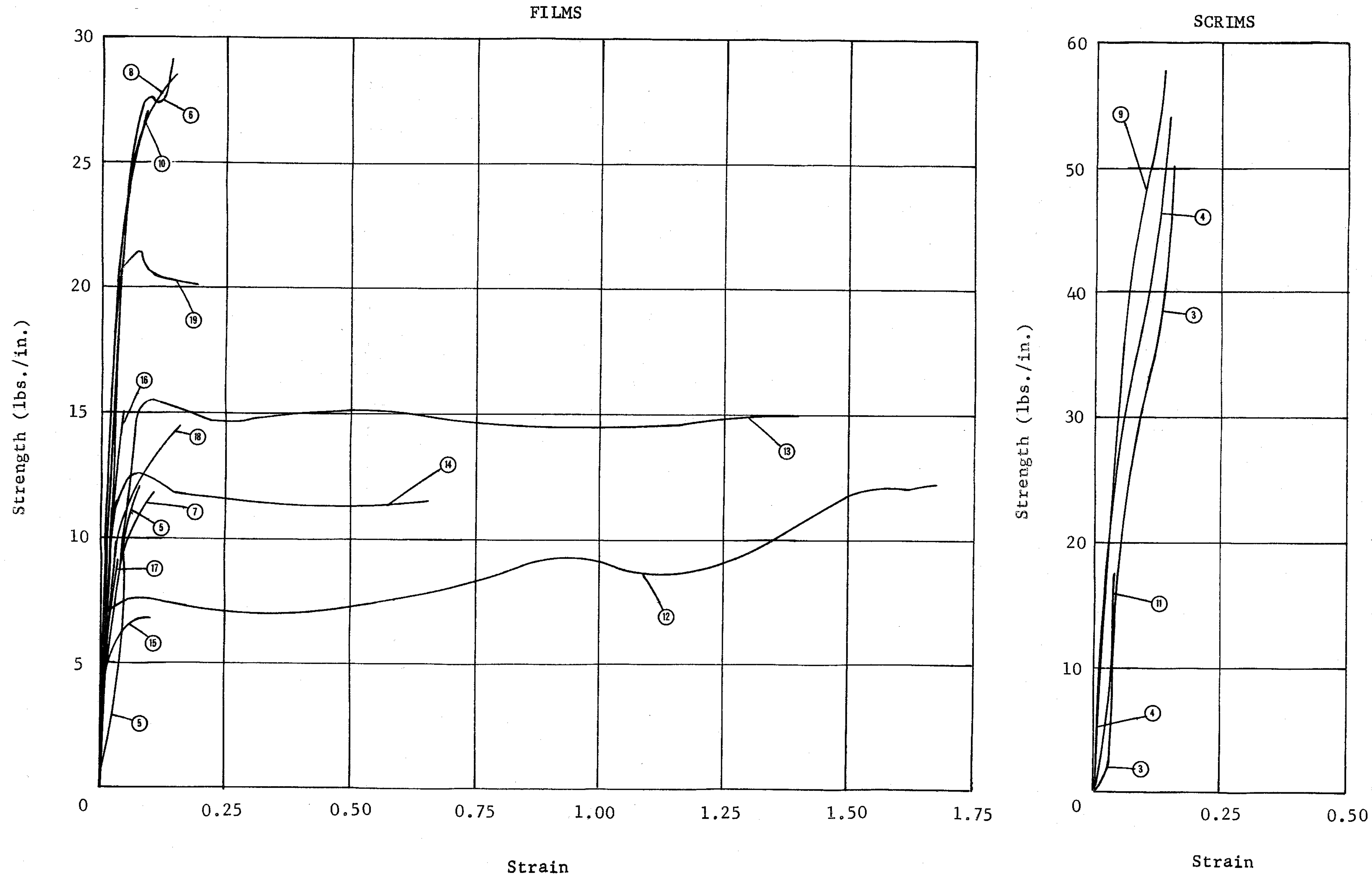


Key:

Code	Film	Thk, mils
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
10	3M Polyester	1.0
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 12 TYPICAL TENSILE CURVES, -80° C.

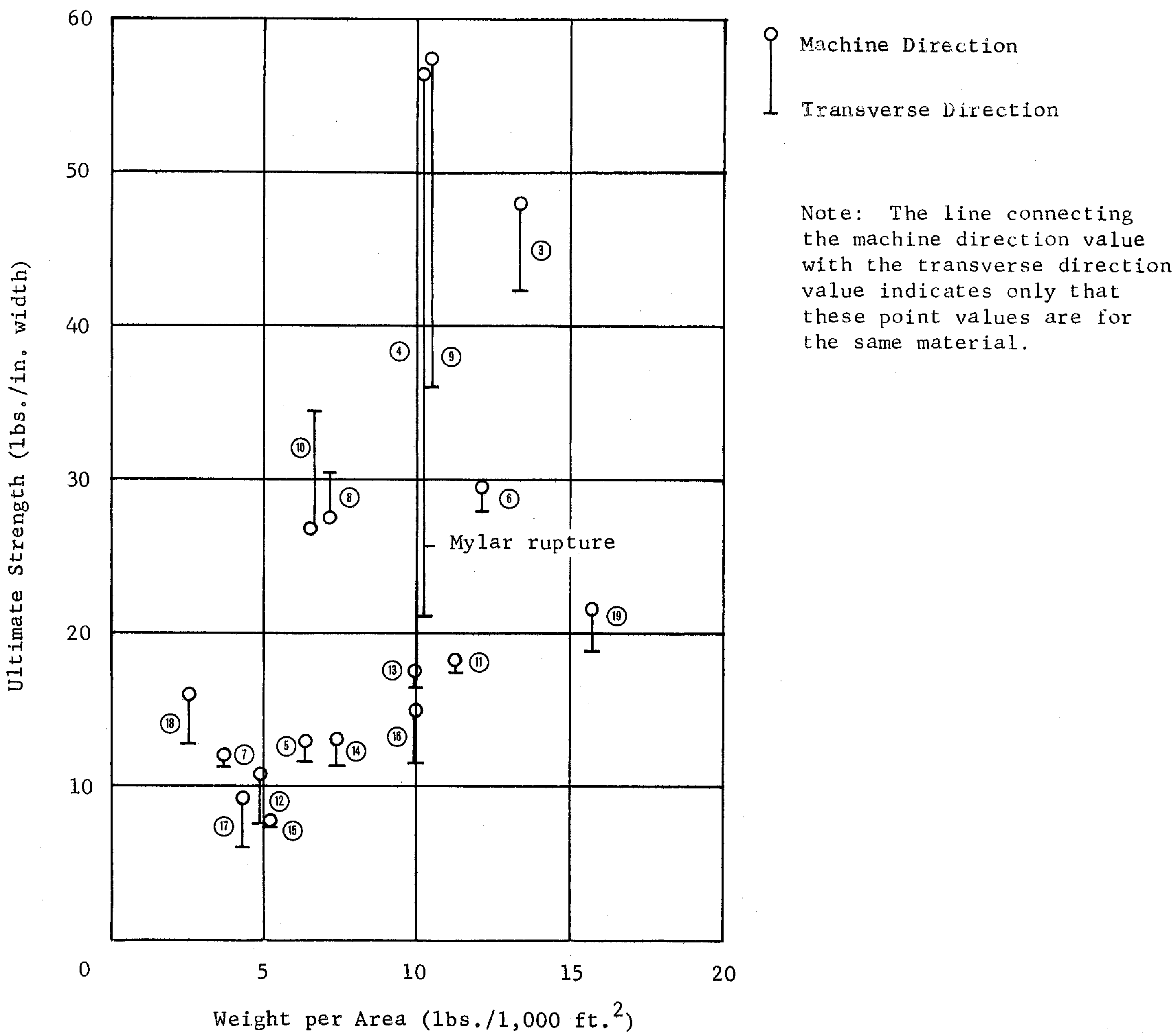
Machine Direction



Key:

Code	Film	Thk, mils
3	Raven 2A-2072	-
4	Raven 2A-1925	-
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
9	Schjeldahl GT-12	-
10	3M Polyester	1.0
11	3M Scrim	-
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 13 STRENGTH VERSUS WEIGHT PER AREA AT -80° C.

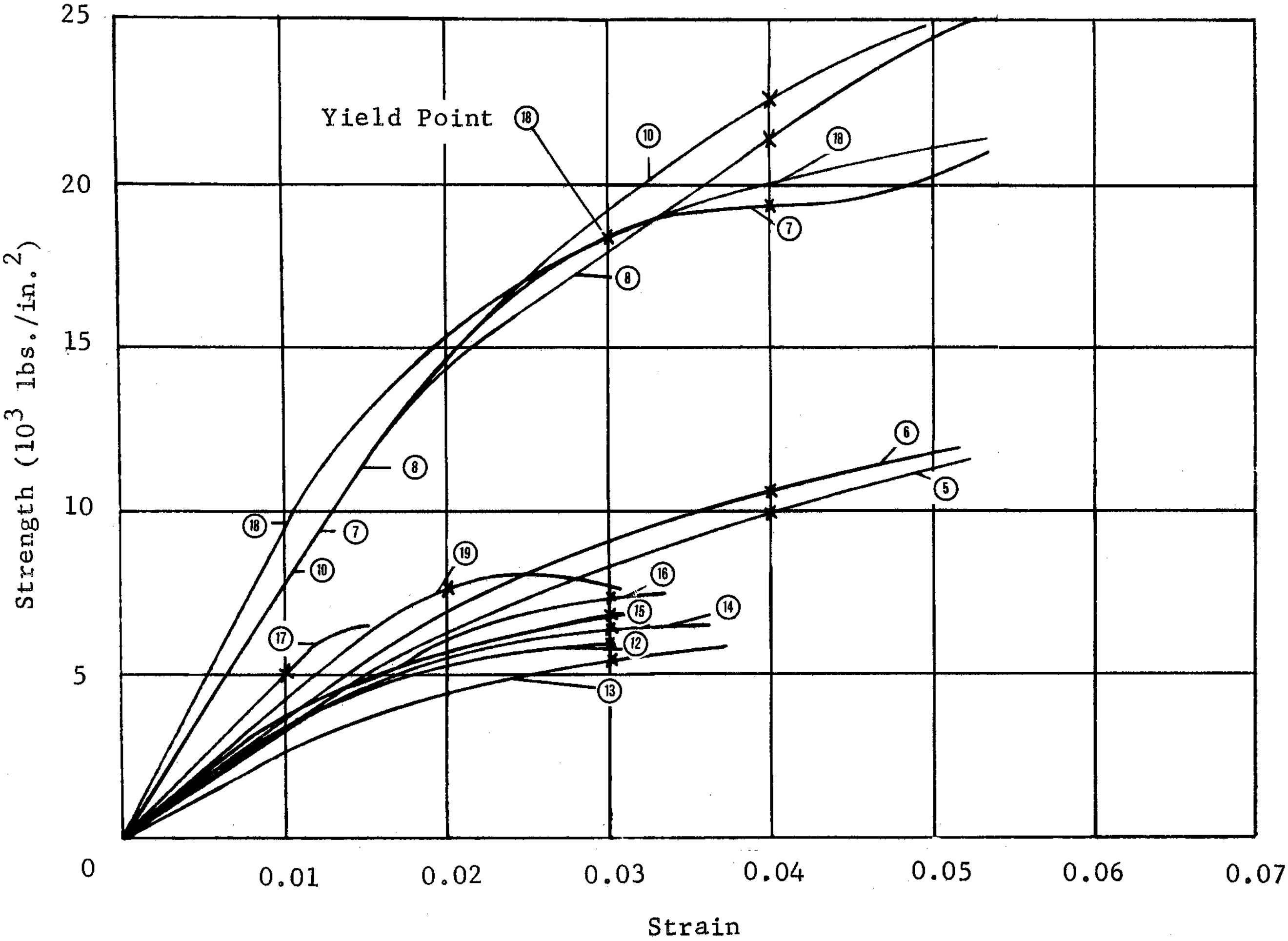


Key:

Code	Film	Thk, mils	Code	Film	Thk, mils
3	Raven 2A-2072	-	12	Consolidated GF19X	1.0
4	Raven 2A-1925	-	13	Consolidated GF19X	2.0
5	Lexan	1.0	14	Vis-Queen A	1.5
6	Lexan	2.0	15	Consolidated SF444	1.0
7	Mylar	0.5	16	Consolidated SF444	2.0
8	Mylar	1.0	17	Cast Polypropylene	1.0
9	Schjeldahl GT-12	-	18	Biax Polypropylene	0.5
10	3M Polyester	1.0	19	Mobay Texin	2.5
11	3M Scrim	-			

Figure 14 TYPICAL MODULUS CURVES, -80° C.

Machine Direction



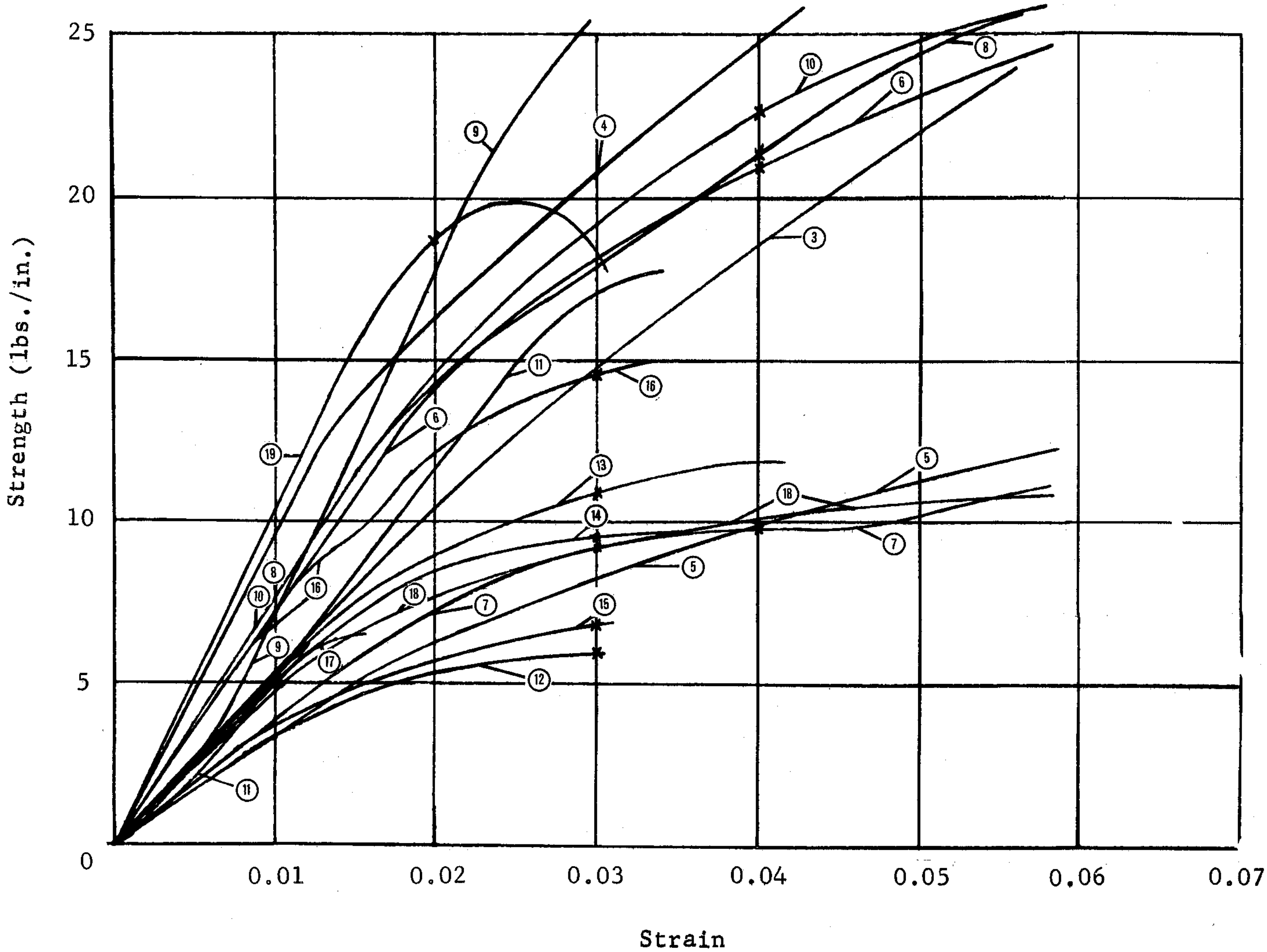
x = Yield Point

Key:

Code	Film	Thk, mils
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
10	3M Polyester	1.0
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 15 TYPICAL MODULUS CURVES, -80° C.

Machine Direction

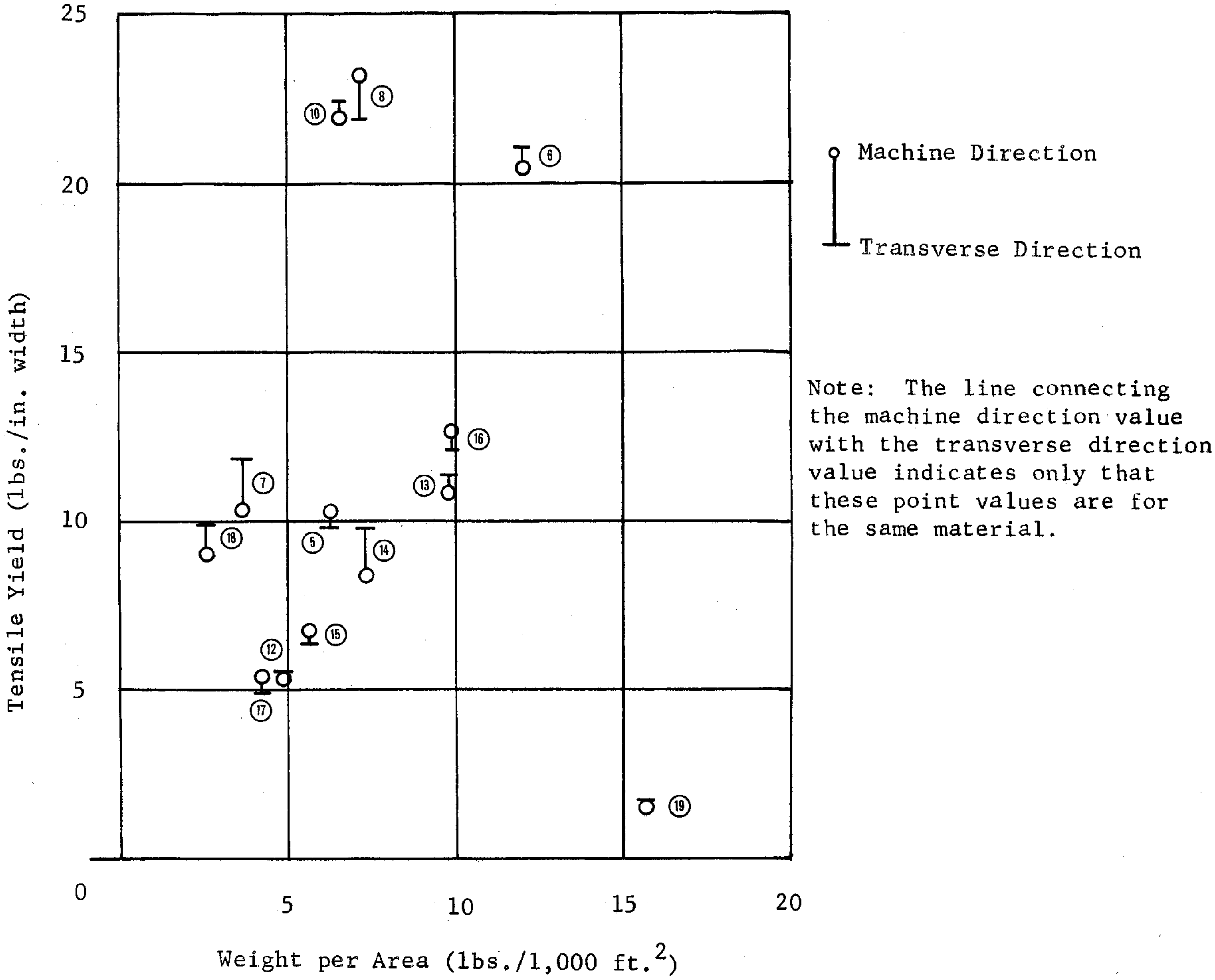


x = Yield Point

Key:

Code	Film	Thk, mils	Code	Film	Thk, mils
3	Raven 2A-2072	-	12	Consolidated GF19X	1.0
4	Raven 2A-1925	-	13	Consolidated GF19X	2.0
5	Lexan	1.0	14	Vis-Queen A	1.5
6	Lexan	2.0	15	Consolidated SF444	1.0
7	Mylar	0.5	16	Consolidated SF444	2.0
8	Mylar	1.0	17	Cast Polypropylene	1.0
9	Schjeldahl GT-12	-	18	Biax Polypropylene	0.5
10	3M Polyester	1.0	19	Mobay Texin	2.5
11	3M Scrim	-			

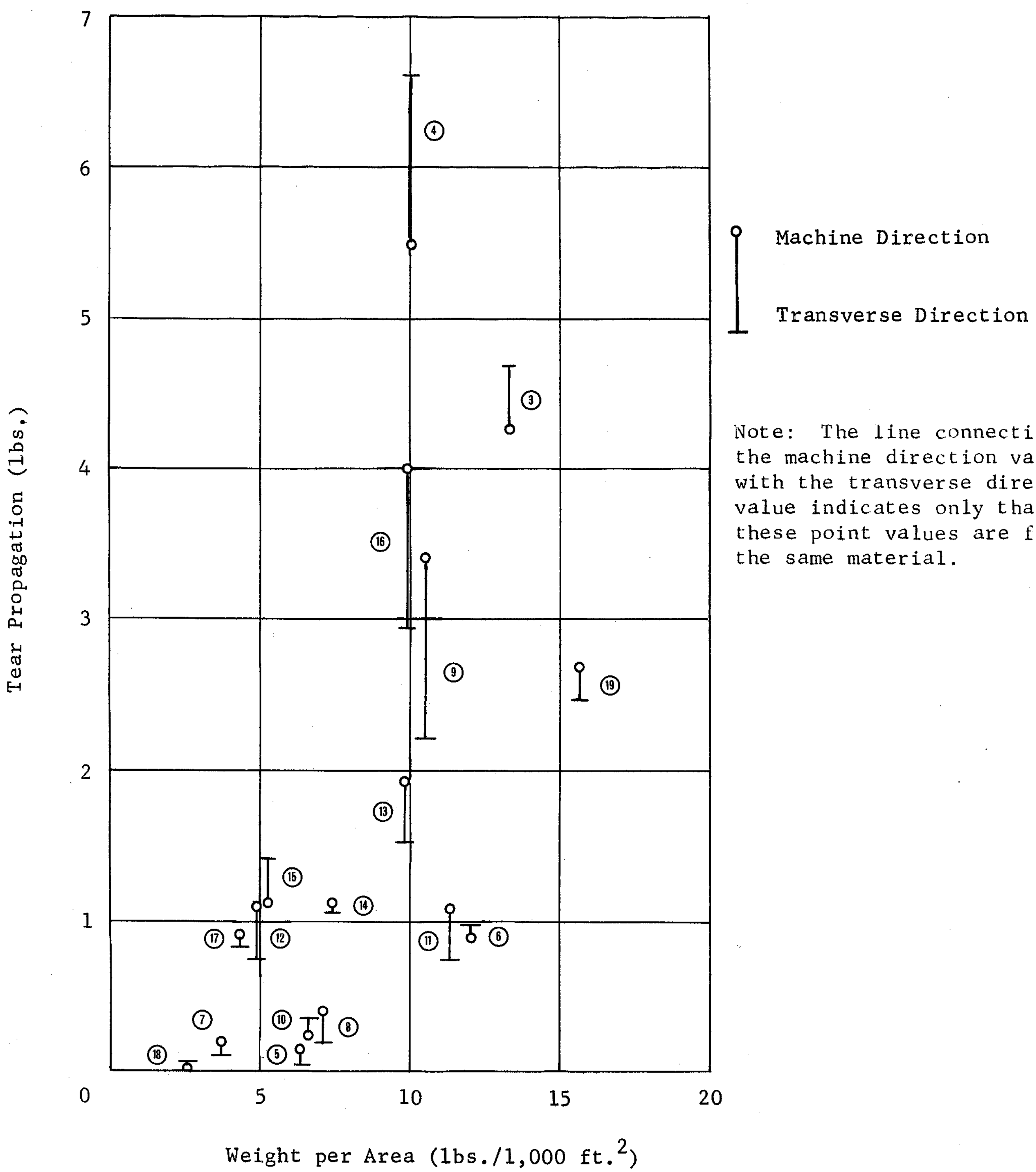
Figure 16 TENSILE YIELD VERSUS WEIGHT PER AREA AT -80° C.



Key:

Code	Film	Thk, mils	Code	Film	Thk, mils
5	Lexan	1.0	14	Vis-Queen A	1.5
6	Lexan	2.0	15	Consolidated SF444	1.0
7	Mylar	0.5	16	Consolidated SF444	2.0
8	Mylar	1.0	17	Cast Polypropylene	1.0
10	3M Polyester	1.0	18	Biax Polypropylene	0.5
12	Consolidated GF19X	1.0	19	Mobay Texin	2.5
13	Consolidated GF19X	2.0			

Figure 17 TEAR PROPAGATION VERSUS WEIGHT PER AREA AT -80° C.

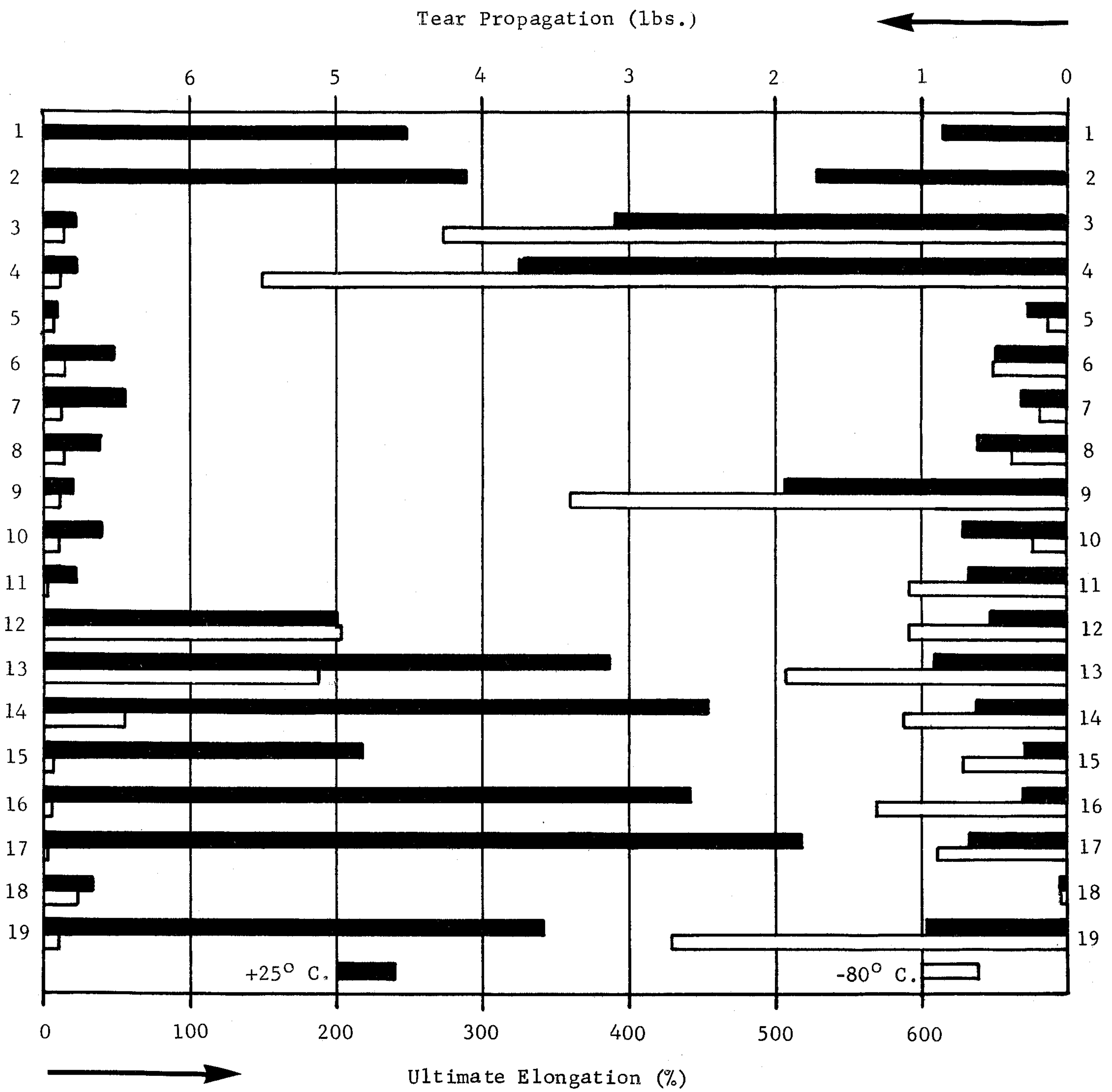


Note: The line connecting the machine direction value with the transverse direction value indicates only that these point values are for the same material.

Key:

Code	Film	Thk, mils	Code	Film	Thk, mils
3	Raven 2A-2072	-	12	Consolidated GF19X	1.0
4	Raven 2A-1925	-	13	Consolidated GF19X	2.0
5	Lexan	1.0	14	Vis-Queen A	1.5
6	Lexan	2.0	15	Consolidated SF444	1.0
7	Mylar	0.5	16	Consolidated SF444	2.0
8	Mylar	1.0	17	Cast Polypropylene	1.0
9	Schjeldahl GT-12	-	18	Biax Polypropylene	0.5
10	3M Polyester	1.0	19	Mobay Texin	2.5
11	3M Scrim	-			

Figure 18. ULTIMATE ELONGATION AND TEAR PROPAGATION VALUES FOR MACHINE DIRECTION AT + 25° C. AND -80° C.



Key:

Code	Film	Thk, mils
1	Allied Capran	1.0
2	Allied Capran	2.0
3	Raven 2A-2072	-
4	Raven 2A-1925	-
5	Lexan	1.0
6	Lexan	2.0
7	Mylar	0.5
8	Mylar	1.0
9	Schjeldahl GT-12	-
10	3M Polyester	1.0
11	3M Scrim	-
12	Consolidated GF19X	1.0
13	Consolidated GF19X	2.0
14	Vis-Queen A	1.5
15	Consolidated SF444	1.0
16	Consolidated SF444	2.0
17	Cast Polypropylene	1.0
18	Biax Polypropylene	0.5
19	Mobay Texin	2.5

Figure 19 RADIANT ENERGY TRANSMISSION OF POLETHYLENE, ETHYLENE COPOLYMER, AND POLYAMIDE FILMS

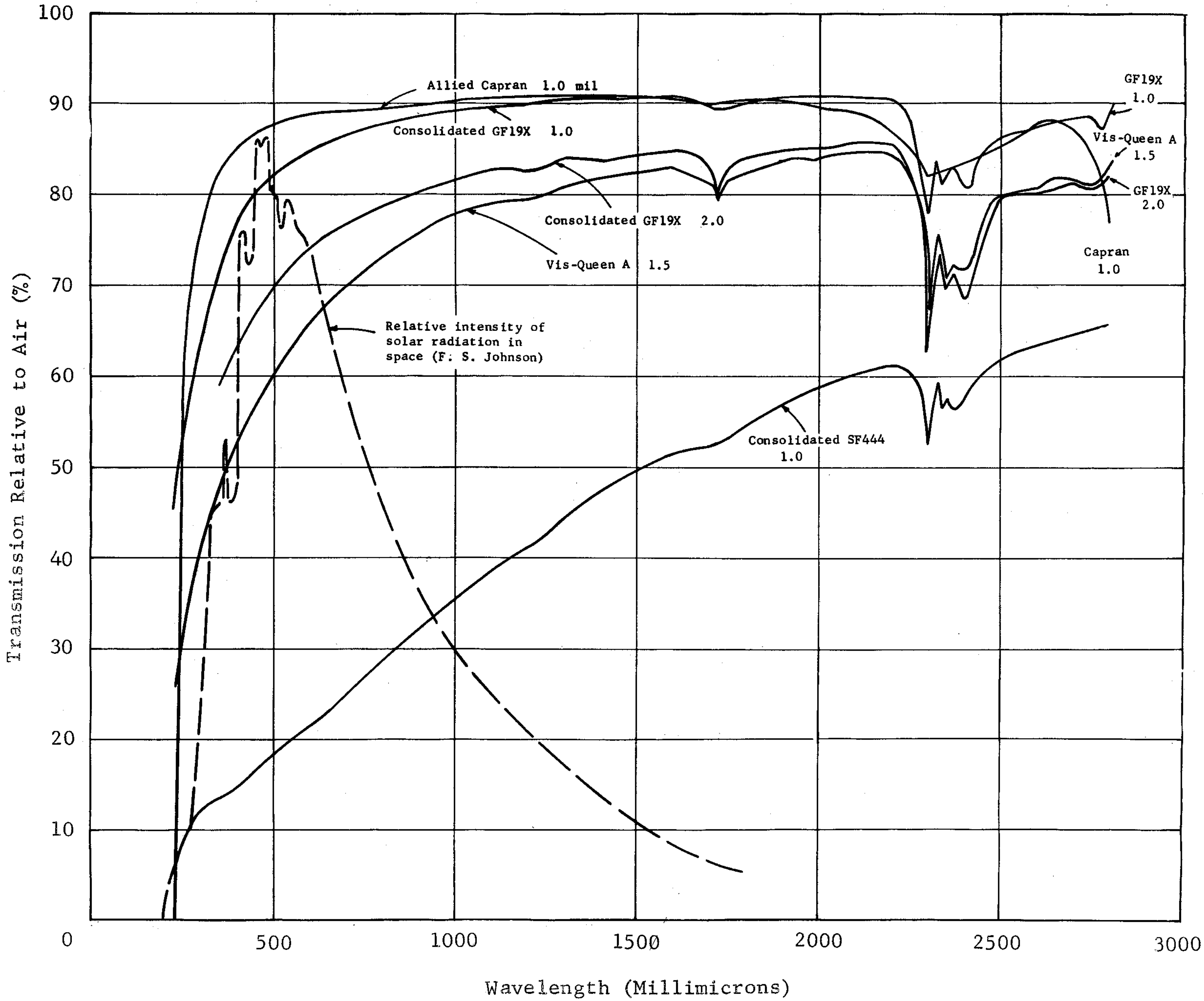


Figure 20 RADIANT ENERGY TRANSMISSION OF POLYPROPYLENE AND POLYESTER FILMS.

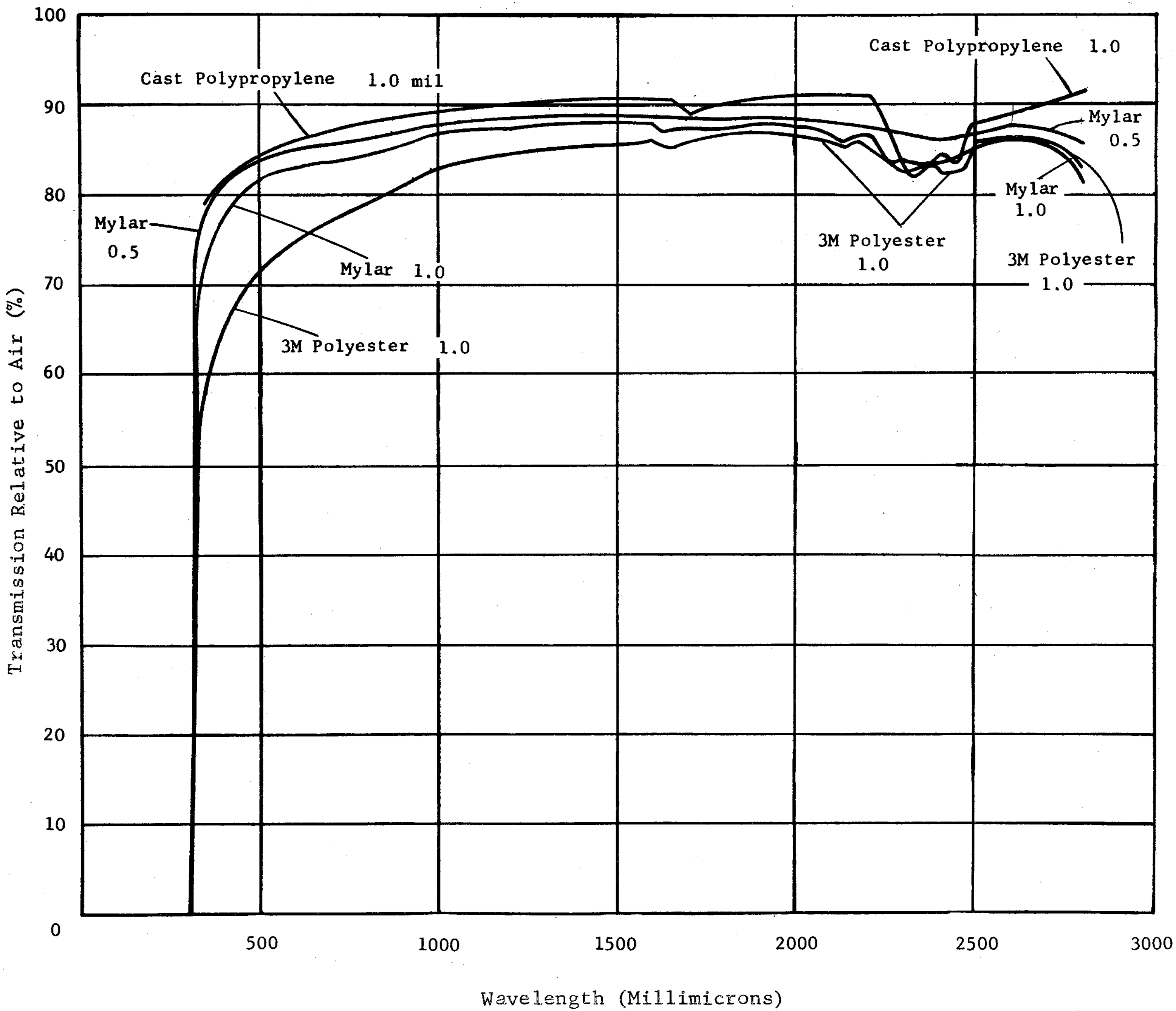


Figure 21 RADIANT ENERGY TRANSMISSION OF POLYCARBONATE AND POLYURETHANE FILMS.

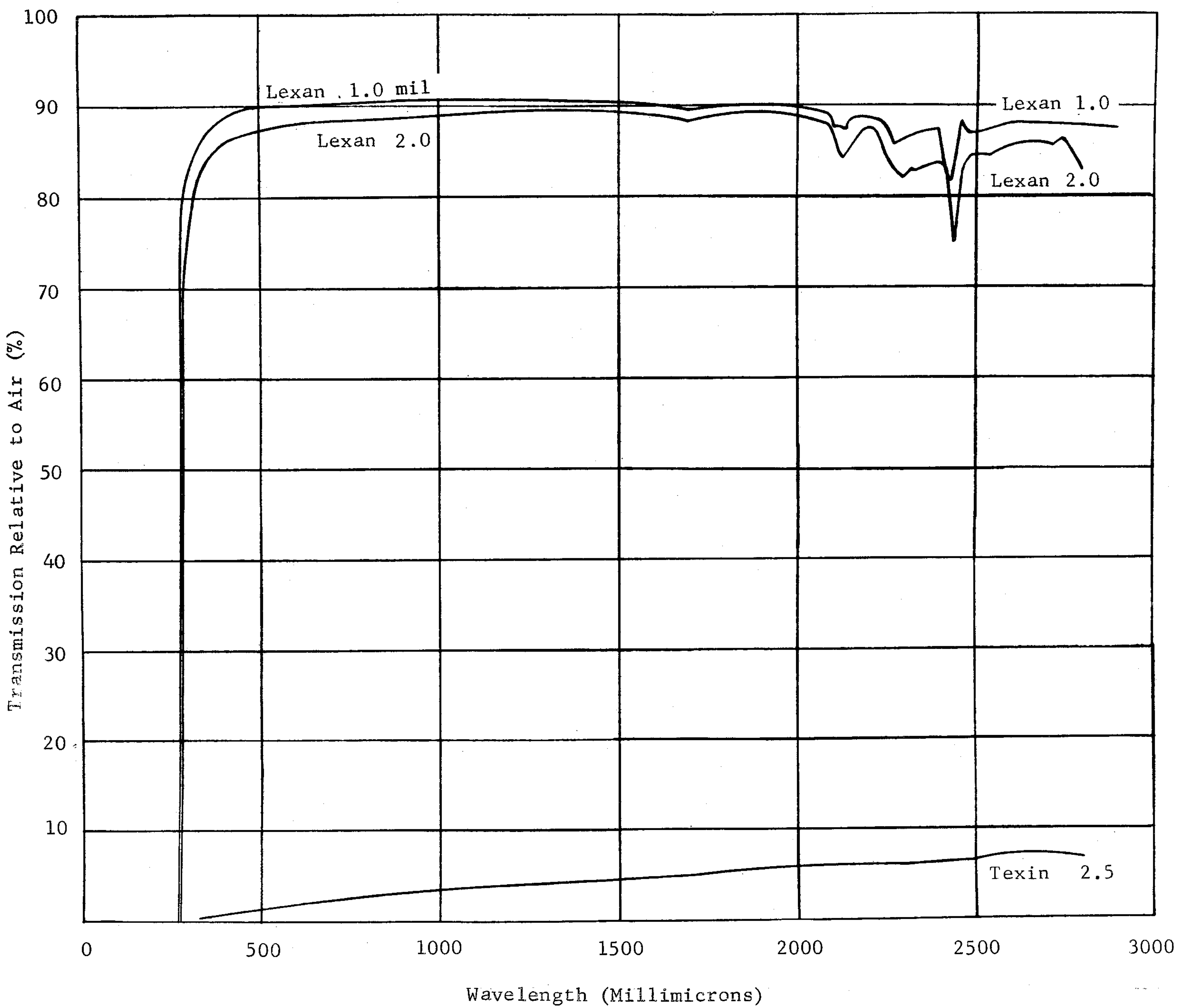


Figure 22 "HAUSER" MODIFICATION OF GRAVES SPECIMEN FOR TEAR PROPAGATION.