

Effect of Strain Rate on the Viscoelastic Properties of High Polymeric Fibrous Materials

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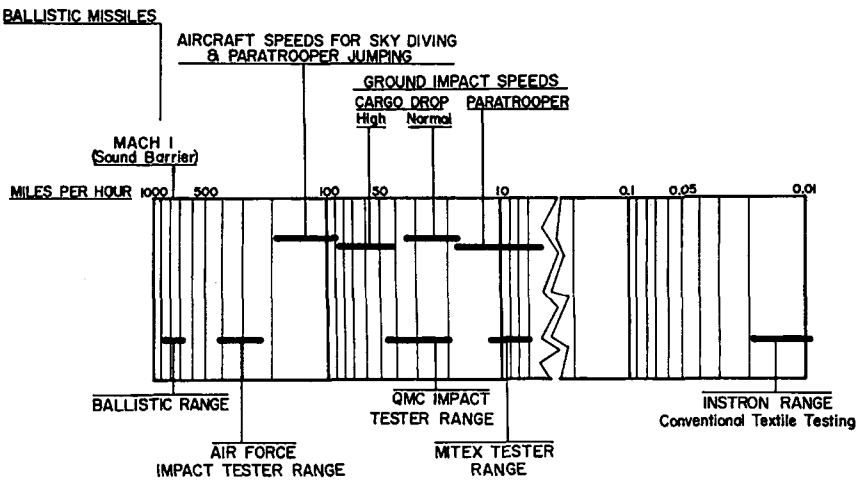
Synopsis

Stress-strain measurements have been made at a relatively low strain rate (100%/min.) and at relatively high strain rates (approximately $260 \times 10^3\%$ /min.) on a series of high polymeric materials of different chemical composition in textile yarn form. The series comprises the following classes of materials: polyacrylic, polyamide, polyester, polymodacrylic, polyolefin, polypeptide, polyurea, polyurethane, polyvinylidene chloride, rubber, and glass. The yarns, with a few exceptions, were conventional continuous filament, low twist structures of varied filament count and denier. Polyvinylidene chloride was tested both as a monofil and also in the form of a slit film. Polyethylene was tested as a monofil. Two polyurethanes and the rubber were tested as monofil with and without cotton covering. From the results of the stress-strain measurements there were calculated values for the following properties at two strain rates: tenacity and elongation at break, work-to-break, and initial modulus. The effects of increased strain rate on these properties are shown. In general, increased strain rate increases the tenacity and initial modulus. These changes are usually, but not always, accompanied by decreases in elongation at break, so that the work to break may either decrease or increase with increasing strain rate. The physical form in which the yarns were tested (denier, number of filaments, conventional yarns versus slit film type) appeared to have only slight effect on their behavior at different strain rates. However, the chemical nature of the polymer molecules and their physical organization within the yarn filaments both have appreciable effects on yarn behavior at different strain rates. The first effect, that due to chemical nature, is exemplified by silk. The behavior of this natural polypeptide, which contains an appreciable number of side chains attached to the main polymer chain, differs markedly, as the strain rate is increased, from the behavior of polyamides which do not contain such side chains. The side chains evidently tend to keep the main polymer chains apart and thus the interchain forces in the polypeptide differ greatly from the interchain forces in polyamides which do not have such side chains. The second effect, that due to the physical organization (crystallinity and degree of orientation) of polymer molecules within a fiber, is demonstrated by a comparison of the behavior of undrawn and regular nylon at low and high strain rates. The stress-strain behavior of the other polymers in yarn form at different strain rates is discussed in the light of their chemical structure and macromolecular organization.

I. INTRODUCTION

The purpose of this paper is to present data on the behavior of various types of polymeric materials when tested in the form of continuous filaments or yarns at conventional strain rates and at relatively high strain rates.

APPLICATION RANGES



TEST INSTRUMENT RANGES

Fig. 1. High speed and impact velocity ranges. The ranges of application of load are indicated in the upper part, the test ranges in the lower part.

In this paper relatively high strain rates refer to the range of 240×10^3 – 240×10^4 %-strain/min., or a rate jaw separation of approximately 18 ft./sec. This range is of interest to us in that it is within the range of actual application of load to various materials, such as parachute canopy fabrics and other textile components of air-type equipment, in which the U. S. Army and the other Armed Forces have a keen and continuing interest.

The location of this area of interest in the general field of high speed and impact velocity testing is shown in Figure 1. The ranges of application of load are indicated in the upper part of the figure, the test ranges in the lower part. It should be noted that the scale is logarithmic and the units are expressed as miles per hour.

In this work two test ranges were used, the conventional range (Instron) and one higher range (Mitex Tester). Under development is an instrument (QMC Impact Tester) which will extend the test range to higher impact velocities. The instrument has not yet been completed and no data are available from it as yet.

This study is a preliminary one. It is intended to be broad in scope, covering as many types of polymeric materials as feasible, and general and qualitative in nature. At this time no effort has been made to consider actual bond strengths, valence directions, or actual size and shape of the chemical atoms and groups involved in the structure of the various polymers. It is hoped in future studies to investigate these aspects in more detail and to achieve a closer correlation of the structure of a fibrous polymer with its behavior at various strain rates.

II. EXPERIMENTAL DETAILS

A. Materials

1. *Polymeric Types*

The generic polymeric types of materials on which this study is based include one inorganic and ten organic types. In the latter group is one natural high polymer, the polypeptide silk. The remainder of the group comprises man-made fibers, either regenerated cellulosic materials or else truly synthetic materials. The chemical composition of the synthetics ranges from that of relatively simple hydrocarbons, polyolefins, to that of materials containing considerable proportions of oxygen and chlorine. From such a wide variety of chemically differing materials one may expect a wide range of behavior characteristics when these materials are tested in filament or yarn form at varied rates of strain.

2. *Yarn Form*

The materials were tested in the form of continuous filament yarns, either as monofil, or as multifilament yarns. One monofil was a commercial product made by slitting film into long narrow strips and allowing the strips to fold over on themselves longitudinally.

The individual filaments ranged in size from very fine (2.0 denier) to very coarse (1100 denier). The number of filaments in a yarn ranged from one (monofilament) to 175 in the multifilament yarns.

In all yarns tested the twist was very low ranging from practically zero to only 7.0 turns/inch. Thus the effect of this parameter on the behavior of yarns at different rates of strain could not be evaluated.

B. Test Methods

1. *Definitions*

In this study the following properties were determined: tenacity in grams/denier, per cent elongation at break, work-to-break (g.-cm./d.cm.), and initial modulus (g./d.).

In textile terms, denier is defined as the weight in grams of 9,000 meters of fiber, therefore the higher the denier, the coarser the fiber.

Tenacity is the breaking strength expressed in grams per denier. It is related to the breaking strength expressed in psi as shown in Figure 2.

Elongation is the extension of the fiber at break expressed as a percentage of the original length.

Work-to-break was determined by measuring the area under the stress-strain curve and is expressed in terms of g.-cm./denier-cm.

Initial modulus is the slope of the stress-strain curve expressed in terms of grams per denier for very low strains.

Denier—Weight in grams of 9000 meters of fiber

Example:

	<i>Denier</i>	<i>Fiber diameter</i> (mils)
Nylon 66	6	1.07
Polyvinylidene chloride	750	100

Tenacity—Breaking strength expressed in grams per denier

Tensile strength (psi) = Tenacity(gm./den.) \times specific gravity \times 12,800

Example:

Nylon 66	$8.0 \times 1.14 \times 12,800 = 116,736$
Lyra	$0.7 \times 1.21 \times 12,800 = 10,842$

Fig. 2. Definitions.

2. Test Techniques

All yarn samples were conditioned under standard textile testing conditions of $70 \pm 2^\circ\text{F}$. and $65 \pm 2\%$ relative humidity for at least 24 hr. prior to test.

Stress-strain measurements at the conventional strain rate were made using an Instron Tensile Tester under the following conditions:

Number of specimens	10
Gage length (in.)	
Normal yarns	5.0
High elongation yarns	0.5-1.0
Rate of jaw separation (in./min.)	5
Chart speed (in./min.)	20

All jaw breaks were discarded.

A view of the Instron is shown in Figure 3. It will be noted that the jaws shown in the illustration are heavy duty jaws and are not the ones used in testing yarn specimens.

Stress-strain test data at high strain rates were determined by use of the Mitex Tensile Impact Tester. This instrument was designed and built in 1961 by the Textile Division of Massachusetts Institute of Technology under a Quartermaster contract.¹ The tester is operated by a pneumatic-hydraulic system. The upper jaw is fixed; the lower jaw is pulled down by a rod (8-in. maximum stroke) attached to the main cylinder piston. Forces are measured at rates of 1-25 ft./sec. by a piezo-electric type load transducer of 500 lb. maximum capacity (Endevco). A magnetic tape, prerecorded with a sine wave of known length, is used to measure direct strain readings.² The stress and strain signals are fed to a dual beam oscil-

loscope. A permanent record is made with a Polaroid type camera. Details of the instrument are as follows:

Operating system	Pneumatic-hydraulic
Load cell	500 lb. piezo-electric type
Strain	Premarked magnetic tape
Piston velocity (ft./sec.)	1-25
Maximum piston distance (in.)	8
Recording technique	Oscilloscope with Polaroid camera

The following test conditions were used:

Number of specimens	10.0
Gage length (in.)	
Normal yarns	5.0
High elongation yarns	0.5-1.0
Initial distance between jaws (in.)	2.0
Average rate of jaw separation (in./sec.)	220.0
(ft./sec.)	18.3

Use of a 5.0 in. gage length and an initial distance of 2.0 in. between jaws provides 3.0 in. slack in the specimen. This allows the lower jaw of the tester to reach maximum speed before strain is applied to the specimen.

Jaw breaks were discarded.

The Mitex Impact Tester is shown in Figures 4 and 5.

Typical recordings of stress-strain curves obtained in the Mitex are shown in Figure 6. The upper curve represents the load, and the lower curve is the time signal from the premarked magnetic tape. From these traces and the calibration data for the instrument, one can draw the stress-strain curves which are shown later.

Figure 7 shows a comparison of the two test methods.

III. RESULTS AND DISCUSSION

A. Effect of Yarn Size and Shape

The effect of yarn size is shown in Figures 8, 9, and 11.* In conventional yarns, which are made up of filaments having circular cross sections, an increase in denier results in an increase in tenacity even when expressed in

* In these and subsequent figures, the solid lines represent the results obtained at conventional strain rates; the dotted lines represent the results obtained at high strain rates.

terms of g./denier. The effect appears to be less at the high strain rate than it is at the lower strain rate.

Occasionally, yarns are not made by the conventional extrusion process but are formed by cutting film into strips and allowing the strips so produced to fold in on themselves. Photomicrographs of one such yarn are shown in

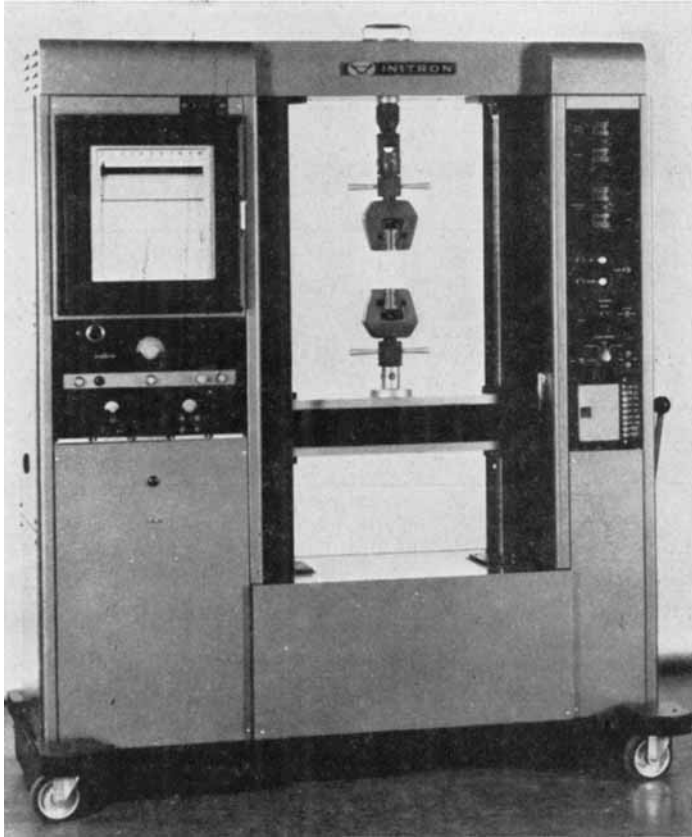


Fig. 3. A view of the Instron.

Figure 10, in comparison with those of a conventional monofilament yarn having the same chemical composition.

Stress-strain curves for these yarns are shown in Figure 11. The shapes of the curves are similar at both test rates. However, the slit-film yarn, which has a denier of 400, has an appreciably higher tenacity than the conventional yarn (750 denier). When two slit-film yarns are compared (Fig. 12), it is seen that the one having the lower denier has the higher tenacity throughout the whole strain range.

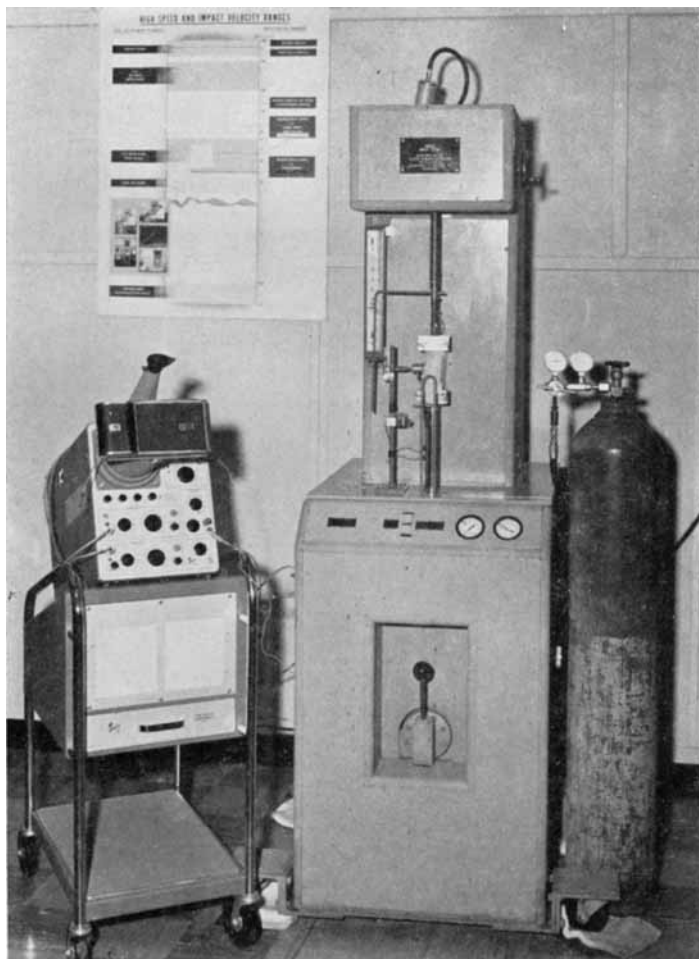


Fig. 4. The Mitex Impact Tester.

B. Effect of Chemical Structure

1. Polyolefins

The simplest of the polymeric materials investigated in this study are the polyolefins, polyethylene and polypropylene. The structures of their monomeric units are shown diagrammatically in Figure 13.

It is pointed out that, in this and subsequent figures, no effort has been made to show relative bond lengths or angles between bonds. In this paper consideration has been limited to the effect of chemical composition and complexity of the polymeric systems.

Polyethylene may be considered as being composed entirely of long carbon chains with two hydrogen atoms attached to each carbon. The chains

are thought to be straight, i.e., *not* branched, with no crosslinks between them.

In polypropylene every second hydrogen atom has been replaced by a methyl group ($-\text{CH}_3$). The methyl groups in isotactic polypropylene are considered to be arranged systematically as indicated in the diagram. In atactic polypropylene the methyl groups are arranged in a perfectly

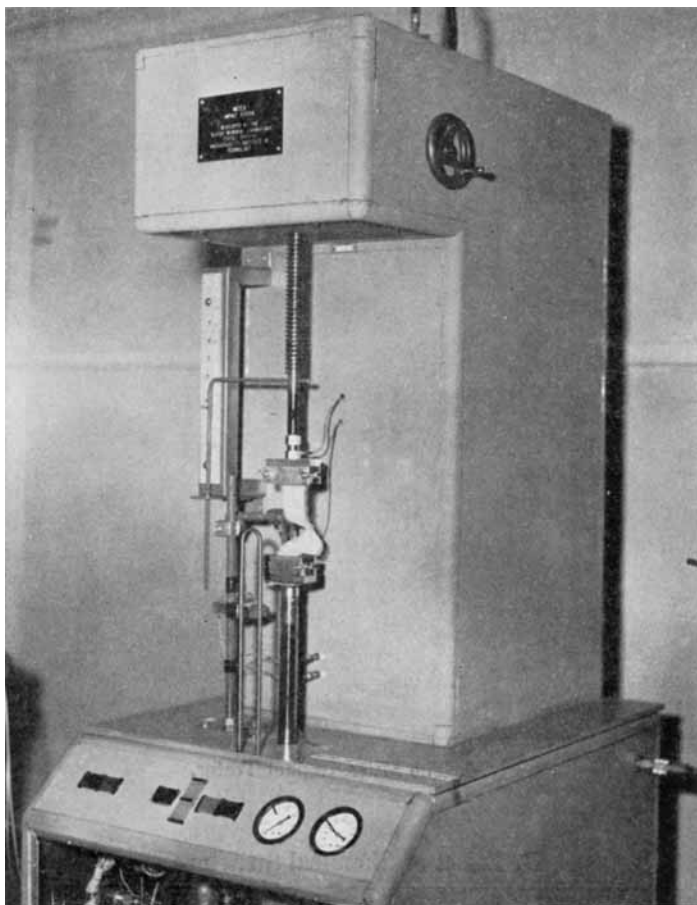


Fig. 5. The Mitex Impact Tester (detail).

random order and, as a result, the polymer is amorphous and has no fiber-forming properties. In syndiotactic polypropylenes there is a partial ordering of the arrangement of the methyl groups but not sufficient to produce good fibers.

The regular introduction of the methyl group into the molecule in place of hydrogen has a marked effect on fiber properties (Fig. 14). Initial modulus and tenacity are increased sharply; elongation at break is decreased and work-to-break is increased.

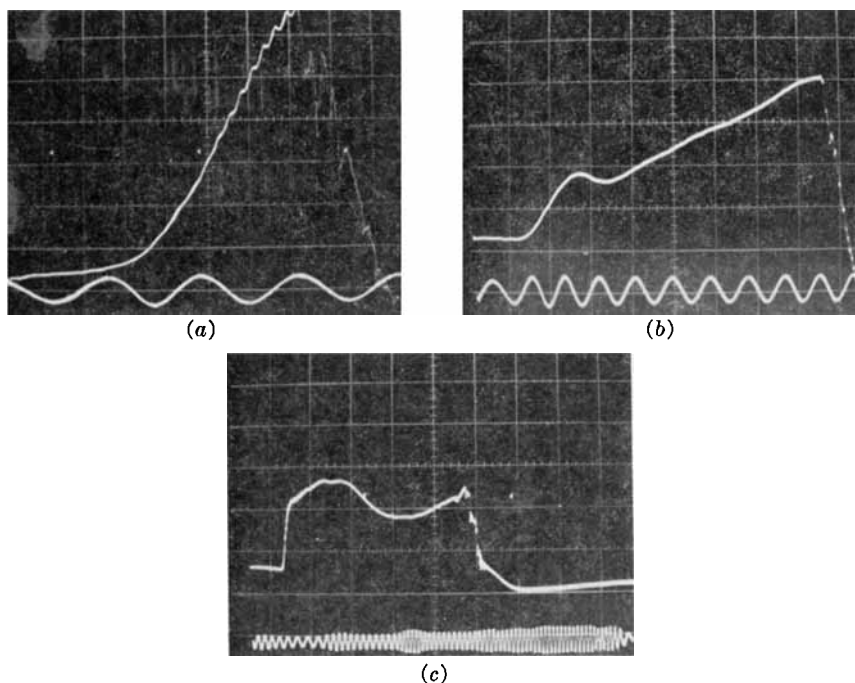


Fig. 6. Typical Mitex high-speed stress-strain curves: (a) fiberglass: sweep rate (ms./cm.) = 0.2, gage length (in.) = 5.0; (b) polyvinylidene chloride: sweep rate (ms./cm.) = 1.0, gage length (in.) = 5.0; (c) undrawn nylon: sweep rate (ms./cm.) = 5.0; gage length (in.) = 0.5.

Testing at higher strain rate increases the initial modulus and tenacity of both materials slightly. It decreases the elongation of polypropylene slightly and that of polyethylene considerably. Work-to-break is decreased slightly at the higher strain rate.

2. Polyvinylidene Chloride and Polyacrylics

These materials, like the preceding polyolefins, have a main chain consisting entirely of carbon atoms. However, some of the hydrogens have

Instrument	Quasi-Static Instron	High Speed Mitex
Rate of jaw separation		
In./min.	5.0	12.0×10^3
Ft./sec.	6.9×10^{-3}	16.7
Gage length (in.)		
Low elongation	5.0	5.0
High elongation	0.5	0.5
Strain rate (%/min.)		
Low elongation	100	240×10^3
High elongation	1000	240×10^4

Fig. 7. Comparison of test methods.

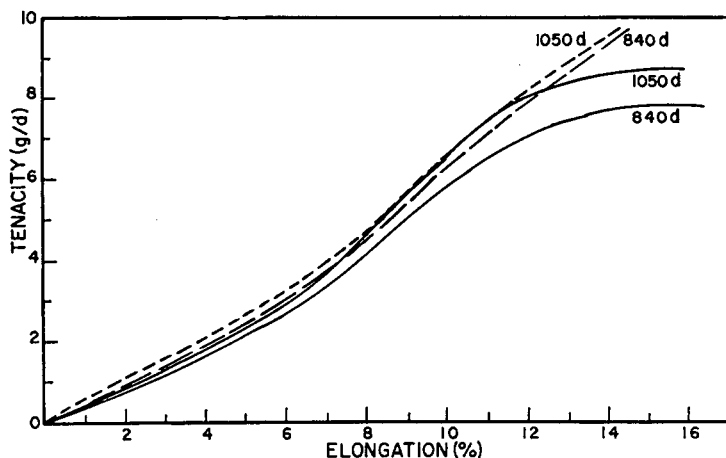


Fig. 8. Effect of yarn size at two strain rates of nylon 6:840 and 1050 denier.

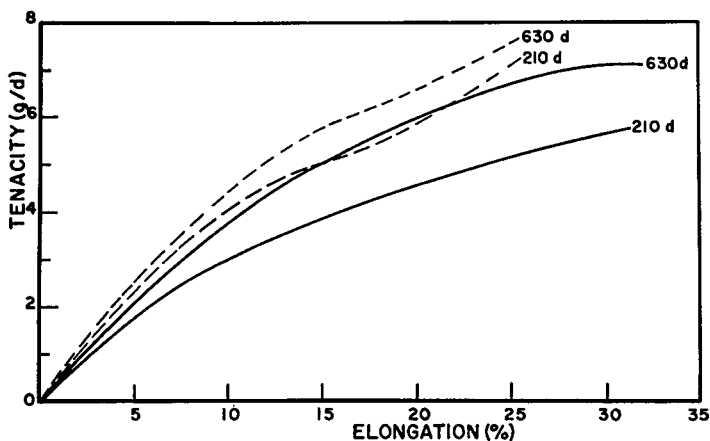


Fig. 9. Effect of yarn size at two strain rates of polypropylene: 210 and 630 denier.

been replaced either by chlorine atoms or by nitrile groups ($-\text{C}\equiv\text{N}$) as indicated in Figure 15.

These substitutions have a very different effect on the stress-strain properties compared to the effect produced by substitution of a methyl group for a hydrogen atom. The stress-strain curves are shown in Figure 16 and from these it can be seen that substitution of a chlorine atom for a hydrogen atom decreases the elongation very much and increases the tenacity little, if any. Substitution of the nitrile group for hydrogen, also decreases the elongation but it increases the tenacity, so that the work-to-break of the polyacrylics is greater than that of the polyvinylidene chloride.

In both these fiber types, testing at a higher strain rate causes an increase in initial modulus and in tenacity, but decreases the elongation at break so

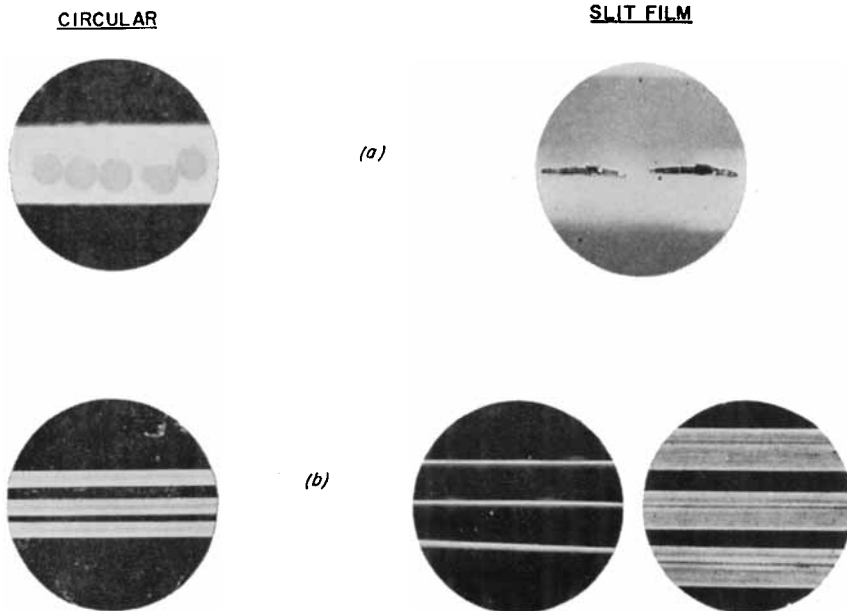


Fig. 10. Photomicrographs of polyvinylidene chloride fiber: (a) cross sectional view 50 \times ; (b) longitudinal view, 25 \times .

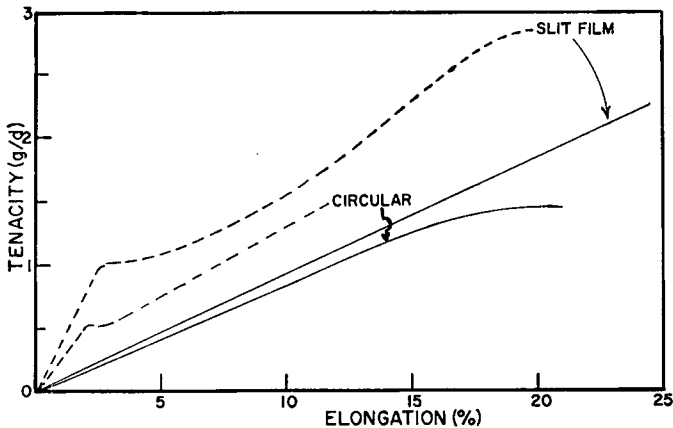


Fig. 11. Effect of yarn form at two strain rates of polyvinylidene chloride: slit film and circular.

that the work-to-break is only slightly higher at the high strain rate than at the low rate.

3. Polyamides

The polyamides represent a different class of polymers from those considered so far. In these, there no longer is a continuous carbon chain

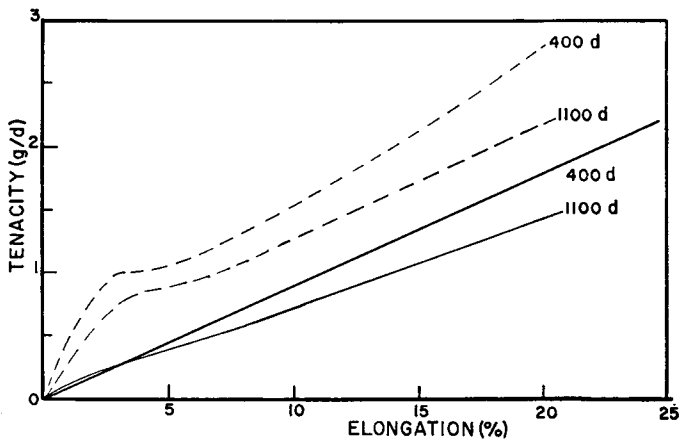


Fig. 12. Effect of yarn size at two strain rates of polyvinylidene chloride: 400 and 1100 denier.

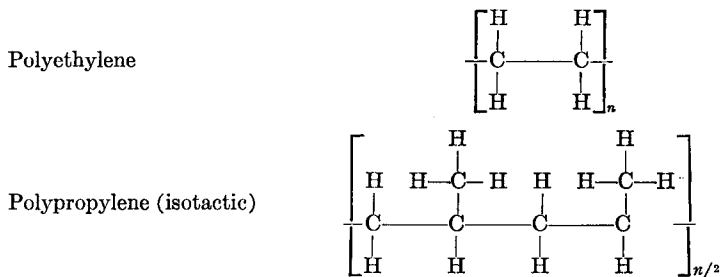


Fig. 13. Monomeric units of two polyolefins.

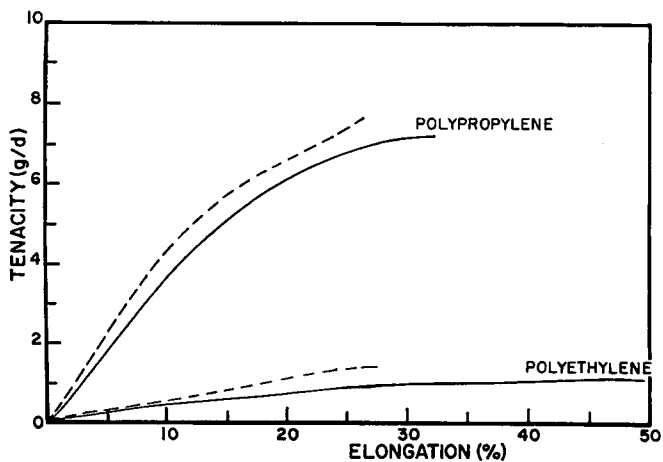


Fig. 14. Effect of strain rate on stress-strain properties of continuous filament yarns of polypropylene and polyethylene.

forming the backbone of the polymer. Instead, the carbon chain is interrupted at regular intervals by a nitrogen atom in the chain next to a carbon atom to which is attached an oxygen atom. In nylon 66 the amide group

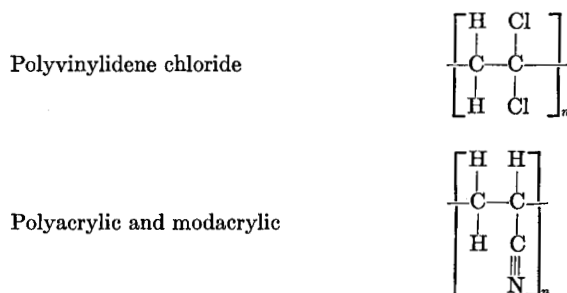


Fig. 15. Replacement of some of the hydrogen atoms by chlorine or by nitrile groups.

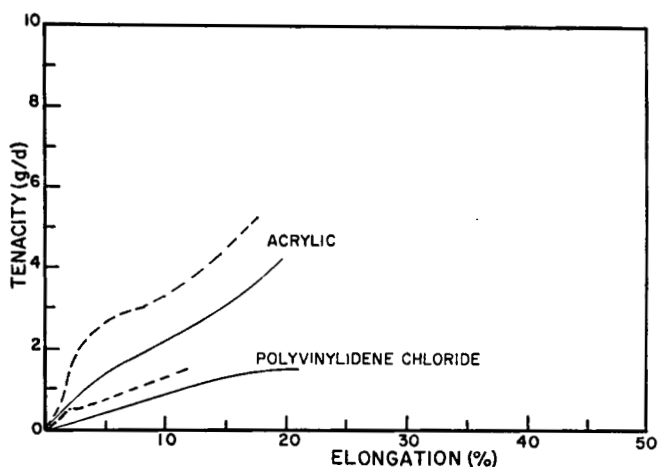


Fig. 16. Effect of strain rate on stress-strain properties of continuous filament yarns of polyvinylidene chloride and acrylic.

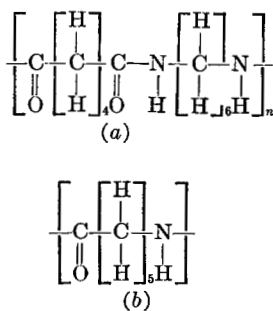


Fig. 17. Structures of two polyamides: (a) nylon 66, (b) nylon 6.

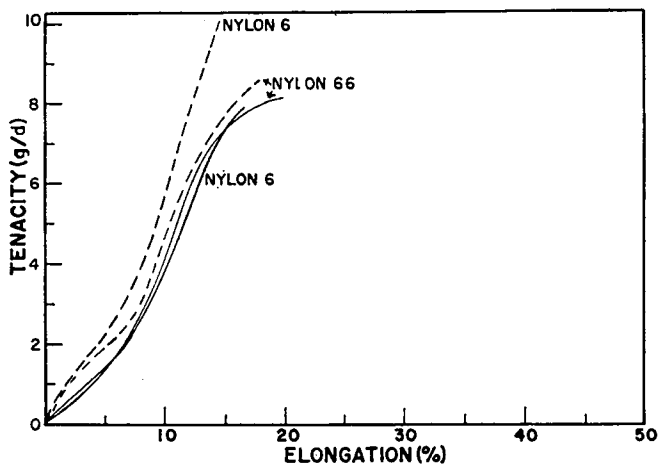


Fig. 18. Effect of strain rate on stress-strain properties of continuous filament yarns of nylon 6 and nylon 66.

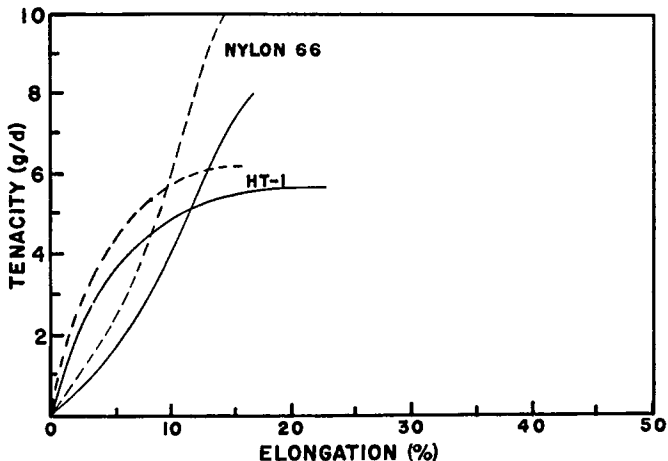


Fig. 19. Effect of strain rate on stress-strain properties of continuous filament yarns of nylon 66 and HT-1.

$$\begin{array}{c} \text{H} \\ | \\ (-\text{C}-\text{N}-) \\ || \\ \text{O} \end{array}$$
 occurs at regular intervals with alternately four and six

methylene groups ($-\text{CH}_2$) between the amides. In nylon 6 the intervals between the amide groups always contain five methylene groups. Thus, although they have the same ultimate composition of carbon, nitrogen, hydrogen and oxygen, the structures of the two polymers are different. This is reflected in the behavior of nylon yarns when tested under different strain rates. This is shown by the stress-strain curves in Figure 18. It

will be noted that these yarns have higher initial moduli and tenacity than any examined so far. At a low strain there is little difference except that nylon 6 has slightly lower elongation at break. At higher strain rates both materials show higher modulus and tenacity with slightly lower per cent elongation. The changes are such that nylon 6 has somewhat higher work-to-break than nylon 66 at the higher strain rate.

The greater strength of the nylons is attributed to a strong attraction (hydrogen bonding) between the hydrogen on an amide nitrogen of one polymer chain and the oxygen in the amide groups in a neighboring chain. This is not a true chemical crosslink but it forms a strong mutual attraction between neighboring polymer chains and considerably enhances fiber strength.

In passing, fiber HT-1 should be mentioned. This is a modified nylon. The stress-strain curves in Figure 19 show it to have a considerably higher modulus and somewhat greater elongation than regular nylon 66, although its tenacity is somewhat less. At the higher strain rate the tenacity of HT-1 increases and its elongation decreases. These changes give it a slightly higher work-to-break at the higher strain rate.

4. Effect of Orientation in Polyamides

It was stated that the high tenacity of nylon 66 and nylon 6 is attributed to hydrogen bonding between polymer chains. In order for this to occur effectively, the chains must be lined up, or oriented, parallel to each other. This is accomplished by controlled stretching of the nylon filaments (cold drawing) after the fibers have been extruded from a nylon melt and before they are wound up in yarn form. An undrawn nylon yarn is very weak and has very high extensibility. This is shown in Figure 20. It should be noted that, in this figure, the elongation is recorded on a logarithmic scale in order to show the final elongation of the undrawn nylon.

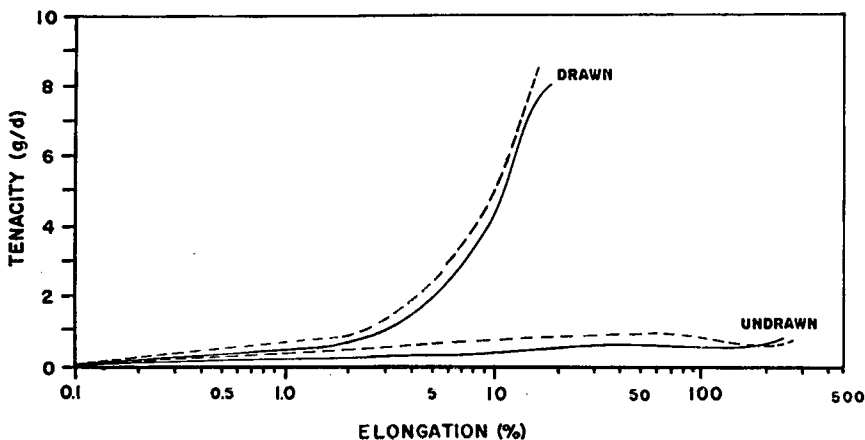


Fig. 20. Effect of strain rate on stress-strain properties of continuous filament yarns of drawn and undrawn nylon 66.

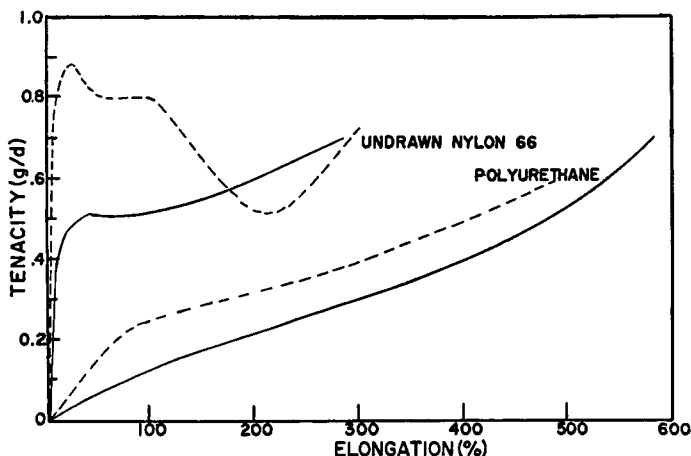


Fig. 21. Effect of strain rate on stress-strain properties of continuous filament yarns of undrawn nylon 66 and polyurethane.

A closer analysis of the undrawn nylon stress-strain curves is very interesting (Fig. 21). At a low strain rate the curve shows a definite yield point at low elongation and then a reinforcing action. At the high strain rate this is greatly exaggerated. The peculiar shape of the curve can be duplicated from sample to sample and does not appear to be an artifact.

5. Polyurethanes

For comparison with undrawn nylon there is shown in Figure 2 the stress-strain curve of a polyurethane. This polymer has a very high elongation and rather low tenacity. At a high strain rate both tenacity and elongation are considerably reduced.

The formula of the polyurethane monomer, shown in Figure 22, is seen to be complex, the main chain now contains not only an amide group but an oxygen atom at regular intervals between methylene groups. The number (x and y) of methylene groups between the amide-oxygen grouping may vary from polyurethane to polyurethane and even in the same polyurethane. Very often, however, x and y are both equal to 4.

The introduction of an oxygen into the main backbone of the polymer molecule has altered the effect of the amide group very markedly, so that the attraction between adjacent chains is greatly reduced and the tenacity of the yarns is decreased very much.

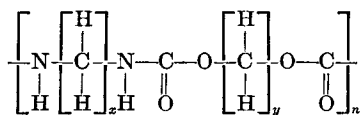


Fig. 22. Formula for the polyurethane monomer.

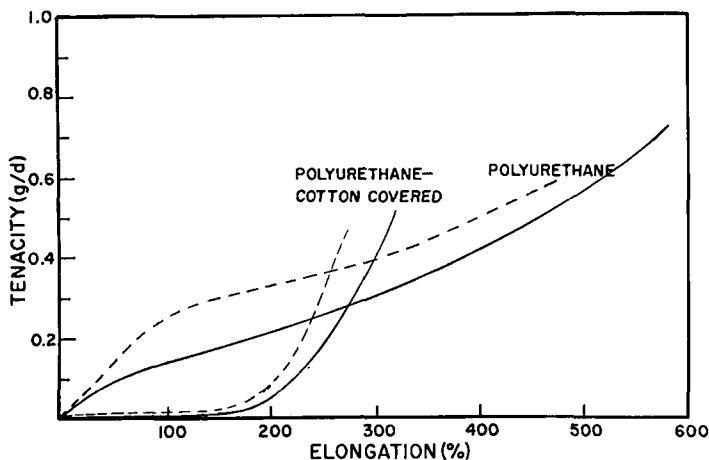


Fig. 23. Effect of strain rate on stress strain properties of continuous filament yarns of polyurethane-cotton covered and polyurethane.

One might wonder as to the commercial utility of such relatively weak yarns. They are normally used with a cotton covering in fabrics where a high elasticity is desirable. As a matter of interest the mechanical effect of the cotton covering on the stress-strain properties of the polyurethanes is shown in Figure 23. Tenacity, elongation and work-to-break are all greatly reduced.

6. Natural Rubber

Although the stress-strain and elastic properties of the polyurethanes resemble those of rubber, their chemical composition is very different. The monomer of natural rubber (Fig. 24) is purely hydrocarbon in nature. It resembles that of the olefins, except that it contains an unsaturated linkage. During polymerization many of the double bonds disappear. During curing, or vulcanization, of the natural rubber undoubtedly more of the double bonds of the main carbon chain are used up in formation of chemical crosslinks between chains. At present, it is not possible to write a satisfactory structural formula for rubber as it exists in a rubber yarn.

The stress-strain properties of rubber yarn are shown in Figure 25. It is seen that they resemble those of polyethylene. The yarns are comparatively weak and have high elongation. Testing at high strain rates decreases tenacity, elongation, and work-to-break.

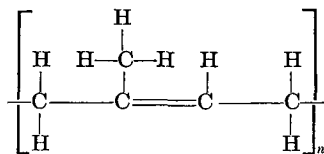


Fig. 24. The monomer of natural rubber.

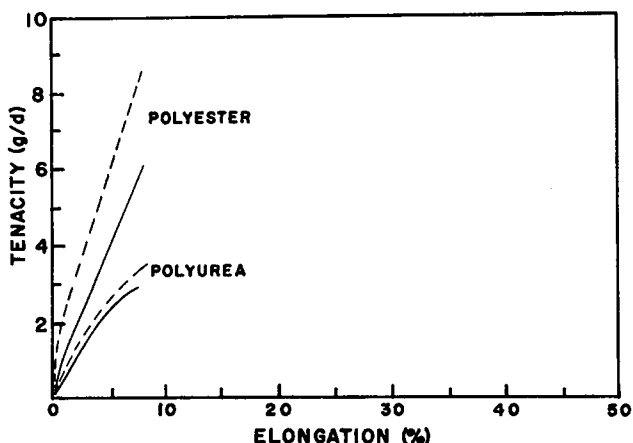


Fig. 27. Effect of strain rate on stress-strain properties of continuous filament yarns of polyester and polyurea.

polyamides, and a much lower elongation than that of either. The urea-type linkage evidently has a marked stiffening effect on the polymer chain.

Another group which has an even more pronounced effect on the polymer chain is that shown in the formula for the polyester monomer in Figure 26, i.e., the phenylene ring with the carboxyl ($-\text{C}-\text{O}-$) linkage on each



side. The phenylene rings, being rather flat in structure, are capable of being packed closely together so that strong interpolymer chain forces can be developed. The effect is shown in Figure 27 where it is seen that the polyester type of yarn has a high tenacity, in the range of the polyamides, but a considerably lower elongation.

Testing at high strain rates increases the modulus, tenacity and work-to-break but lowers the elongation slightly.

8. Cellulosic, Polypeptide, and Glass

These three types of polymeric materials are grouped together because of the complexity of their chemical structures and because of certain similarities in their stress-strain behavior. All have comparatively low elon-

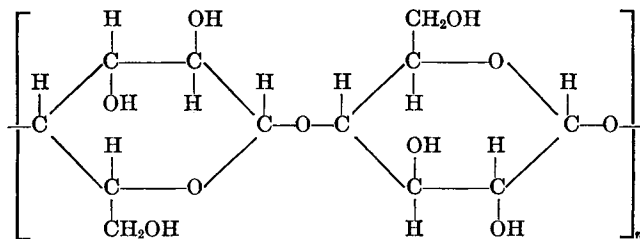


Fig. 28. Repeating monomer in cellulosic materials.

interchain hydrogen bonding forces which would produce very strong fibers having very low elongation. Actually, this is obviated to some extent by the presence of many side chains, indicated as R groups in the diagram. These are derived mainly from the amino acids alanine, serine, and tyrosine from which the polypeptide is formed. Only the tyrosine side chain is especially bulky, since it contains a phenyl group. Nevertheless, these groups provide a certain amount of "padding" between the main chains. Ordinary nylon can be considered as a "bare" polyamide-methylene-chain polymer with 100% of the polymer in the main chain. In silk only approximately 70% of the polymer is in the main polymer chain backbone. The other 30% is in the side chains. This undoubtedly prevents the development of as high interchain bonding between the amide groups as might at first be expected.

So far as glass is concerned it is difficult to write a satisfactory formula. In the diagram shown it is merely intended to indicate that the polymer structure may be a complex of silicon-oxygen chains with many possible crosslinks between chains. This would be expected to lead to a high tenacity, low elongation material.

The stress-strain curves for these polymers are shown in Figure 30. All fibers have high modulus, and relatively low elongation. The cellulosic and glass polymers also have high tenacity. On these two fibers, cellulosic and glass, testing at high strain rates has the usual effect of increasing the modulus and tenacity and decreasing the elongation. The work-to-break is decreased.

In the polypeptide, however, the high strain rate has an unusual effect; it increases *both* the tenacity and the elongation so that the work-to-break is increased measurably. In the polymeric materials examined so far in this study, silk appears to be the only one which behaves in this way. There is no obvious explanation for this fact.

It would be desirable to examine other polypeptide materials, such as keratins in the form of single wool and hair fibers. However, time has not been available in this study to develop a technique suitable for handling single fibers.

IV. SUMMARY

Figure 31 presents a summary of the stress-strain curves determined from data obtained at conventional strain rates. It will be noted that No. 11 (polyurethane) extends far beyond the elongation range of this chart. The curve for rubber has been deliberately omitted as it would fall below the polyurethane curve. The curve for polyurea has been inadvertently omitted. It would be close to curve No. 4 for silk.

The curves illustrate the profound effect of chemical structure on stress-strain properties of polymeric materials. At one extreme there are the comparatively simple hydrocarbon structures either with weak, extensible crosslinks or with little attraction between polymer chains. On the other

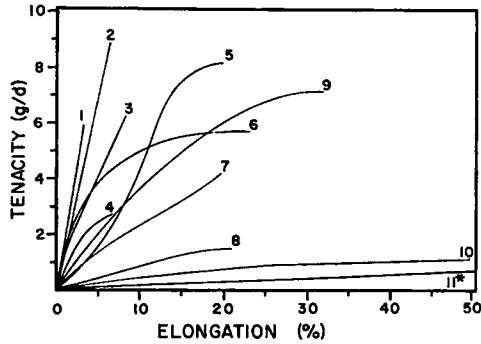


Fig. 31. Stress-strain curves of various continuous filament yarns at low strain rate: (1) fiberglass; (2) cellulosic; (3) polyester; (4) silk; (5) nylon 66; (6) HT-1; (7) acrylic; (8) polyvinylidene chloride; (9) polypropylene; (10) polyethylene; (11) polyurethane (*582 % elongation).

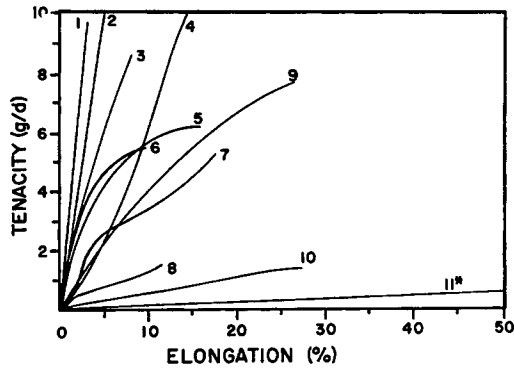


Fig. 32. Stress-strain curves of various continuous filament yarns at high strain rate: (1) fiberglass; (2) cellulosic; (3) polyester; (4) nylon 66; (5) HT-1; (6) silk; (7) acrylic; (8) polyvinylidene chloride; (9) polypropylene; (10) polyethylene; (11) polyurethane (*480 % elongation).

extreme there is the highly crosslinked structure of glass. In between are the cellulosic, polyester, and polyamide structures with more or less opportunity for hydrogen bonding between chains depending on the nature of the groups involved in the main polymer chain and in the side chains and their shape and bulk.

Figure 32 shows the stress-strain curves obtained from tests on the same polymers at high strain rates.

Figure 33 shows in tabular form the effect of strain rate on initial modulus of the various polymer types.

Figure 34 summarizes in bar chart form the values for tenacity, elongation and work-to-break of the various polymers investigated in this study. The effect of higher strain rate may be summarized as follows: (a) increase in initial modulus, (b) increase in tenacity, (c) decrease in elongation in all

Polymeric Material	Initial Modulus (g/d)	
	Low Strain Rate	High Strain Rate
Polyolefin		
Ethylene	5	7
Propylene	42	54
Polyacrylic	35	68
Polyvinylidene chloride	11	36
Polyamide		
Nylon 66	49	61
Nylon 6	53	66
HT-1	110	140
Undrawn nylon 66	5	16
Polyester	120	170
Polyurethane	0.08	0.17
Rubber	0.01	0.01
Polyurea	52	55
Cellulosic	180	250
Polypeptide	50	107
Glass	175	280

Fig. 33. Effect of strain rate on initial modulus of polymeric materials in continuous filament form.

materials except the polypeptide, silk, and (d) changes in work-to-break which may be either increases or decreases depending on the relative changes in tenacity and elongation.

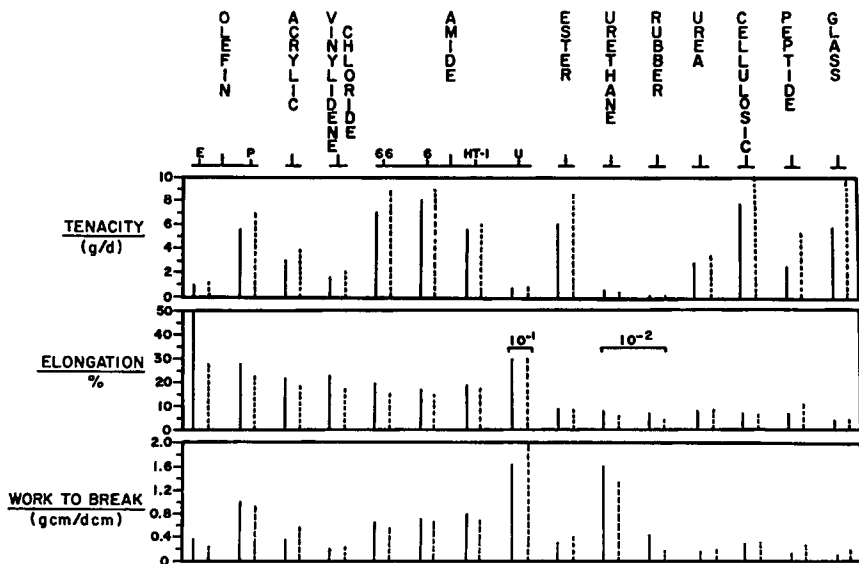


Fig. 34. Effect of strain rate on viscoelastic properties of polymeric materials in continuous filament form.

References

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Résumé

Des mesures de tension-élongation ont été effectuées à des vitesses d'élongation relativement faibles (100%/min) et à des vitesses d'élongation relativement élevées (approximativement $260 \times 10^3\%/min$) sur une série de matériaux fortement polymériques, de compositions chimique différente et sous forme de fibre textile. Les séries comprennent les classes de matériaux suivants: polyacrylique, polyamide, polyester, polyméthacrylique, polyoléfine, polypéptide, polyurée, polyuréthane, chlorure de polyvinylidène, caoutchouc, et verre. Les fibres, à de rares exceptions près, sont des filaments continus conventionnels à structure faiblement tordues de nombre de filaments et deniers variables. Le chlorure de polyvinylidène a été étudié comme monofil et également sous forme d'un film fendu. Le polyéthylène a été étudié comme monofil. Deux polyuréthanes et le caoutchouc ont été étudiés comme monofil avec et sans recouvrement de coton. A partir des résultats des mesures de tension-élongation, on a calculé les valeurs des propriétés suivantes à deux vitesses d'élongation: ténacité et élongation à la rupture, travail nécessaire à la rupture et module initial. On montre les effets d'une augmentation de la vitesse d'élongation sur ces propriétés. En général, l'augmentation de la vitesse d'élongation augmente la ténacité et le module initial. Ces changements sont habituellement, mais pas toujours accompagnés d'une diminution dans l'élongation à la rupture, de telle sorte que le travail de rupture peut diminuer ou augmenter avec l'augmentation de la vitesse d'élongation. La forme physique suivant laquelle les fibres sont étudiées (deniers, nombre de filaments, fibre conventionnelle contre films fendu) semble n'avoir qu'un faible effet sur leur comportement aux différentes vitesses d'élongation. Cependant, la nature chimique des molécules de polymère ainsi que leur organisation physique à l'intérieur des filaments de la fibre, ont des effets appréciables, sur le comportement de la fibre aux différentes vitesses d'élongation. Ce premier effet, dû à la nature chimique est représenté par la soie. Le comportement de ce polypeptide naturel, qui contient un nombre appréciable de chaînes latérales attachées à la chaîne polymérique principale, diffère fortement, lorsqu'on augmente la vitesse d'élongation, du comportement des polyamides qui ne contiennent pas de telles chaînes latérales. Les chaînes latérales tendent évidemment à maintenir les chaînes polymériques principales écartées et par conséquent les forces entre les chaînes dans le polypeptide diffèrent fortement des forces entre les chaînes dans les polyamides, qui ne possèdent pas de telles chaînes latérales. Le second effet, dû à l'organisation physique (cristallinité et degré d'orientation) des molécules de polymère à l'intérieur de la fibre est démontré par la comparaison du comportement entre le nylon non-étiré et régulier à des vitesses d'élongation faibles et élevées. On discute du comportement à la tension-élongation d'autres polymères sous forme de fibre à différentes vitesses d'élongation à la lumière de leur structure chimique et de leur organisation macromoléculaire.

Zusammenfassung

Spannungs-Dehnungsmessungen wurden bei verhältnismässig niedriger (100% pro min) und hoher (etwa $260.10^3\%/min$) Dehnungsgeschwindigkeit an einer Reihe hochpolymerer Stoffe mit verschiedener chemischer Zusammensetzung in Textilgarnform durchgeführt. Untersucht wurden folgende Stoffklassen: Polyacrylat, Polyamid, Polyester, Polymodacrylat, Polyolefin, Polypeptid, Polyurethan, Polyvinylidenchlorid, Kautschuk, und Glas. Die Garne waren mit wenigen Ausnahmen konventionelle kon-

tinuierliche Fäden mit niedriger Verzerrung und verschiedener Fadenzahl und Denier. Polyvinylchlorid wurde als Einzelfaden und in Form eines Films getestet. Polyäthylen wurde als Einzelfaden getestet. Zwei Polyurethane sowie der Kautschuk wurden als Einzelfäden mit und ohne Baumwollüberzug getestet. Aus den Ergebnissen der Spannungs-Dehnungsmessungen wurden Werte für folgende Eigenschaften bei zwei Dehnungsgeschwindigkeiten berechnet: Zähigkeit und Bruchdehnung, Brucharbeit und Anfangswert des Moduls. Der Einfluss einer Erhöhung der Dehnungsgeschwindigkeit auf diese Eigenschaften wird gezeigt. Im allgemeinen erhöht eine grössere Dehnungsgeschwindigkeit die Zähigkeit und den Anfangsmodul. Diese Veränderungen werden gewöhnlich, aber nicht immer, von einer Abnahme der Bruchdehnung begleitet, sodass die Brucharbeit mit zunehmender Dehnungsgeschwindigkeit entweder ab- oder zunehmen kann. Die physikalische Form der getesteten Garne (Denier, Faserzahl, konventionelle Garne oder Spinnfilme) schien nur einen geringen Einfluss auf ihr Verhalten bei verschiedenen Dehnungsgeschwindigkeiten zu haben. Dagegen hat die chemische Natur der Polymermoleküle und ihre physikalische Organisation innerhalb der Garnfasern einen beträchtlichen Einfluss auf das Verhalten des Garns bei verschiedenen Dehnungsgeschwindigkeiten. Der Einfluss der chemischen Natur wird durch Seide belegt. Das Verhalten dieses natürlichen Polypeptides, das an der Hauptkette des Polymeren eine beträchtliche Anzahl von Seitenketten enthält, unterscheidet sich bei zunehmender Dehnungsgeschwindigkeit merklich vom Verhalten von Polyamiden ohne solche Seitenketten. Die Seitenketten haben offenbar die Tendenz, die Hauptketten auseinanderzuhalten, und daher unterscheiden sich die Kräfte zwischen den Ketten bei den Polypeptiden stark von denjenigen bei den Polyamiden, welche keine derartigen Seitenketten besitzen. Der Einfluss der physikalischen Organisation (Kristallinität und Orientierungsgrad) der Polymermoleküle innerhalb einer Faser wird an einem Vergleich des Verhaltens von ungerecktem und normalem Nylon bei niedriger und hoher Verformungsgeschwindigkeit gezeigt. Das Spannungs-Dehnungsverhalten der anderen Polymeren in Garnform bei verschiedener Dehnungsgeschwindigkeit wird im Lichte ihrer chemischen Struktur und makromolekularen Struktur diskutiert.