JOURNAL OF APPLIED POLYMER SCIENCE VOL. 10, PP. 1949-1971 (1966)

Behavior of Fibers in Cumulative Extension Cycling

J. W. S. HEARLE* and H. R. PLONSKER,
Fibers and Polymers Division, Mechanical Engineering Department, Massachusetts Institute of Technology, Cambridge, Massachusetts

Synopsis

The cumulative extension cycling behavior is a combination of the effects of elastic recovery, viscoelasticity, and fatigue. The purpose of this research was to examine the elastic recovery aspects of the behavior. A model behavior idealized to include only elastic recovery was assumed and a computer program written to simulate cumulative extension cycling behavior based upon this idealized model. Tests were performed with an apparatus which removed the sample's slack after each cycle. A comparison of the experimental and computed results yielded an improved understanding of the elastic recovery aspects of the cumulative extension cycling behavior.

INTRODUCTION

One type of loading history which can be applied to a fibrous material—fiber, yarn, or fabric—is cumulative extension cycling, defined as cycling between fixed extension limits but with the slack removed after each cycle. One practical example is the pitching of a tent. Initially the tent fabric is drawn taut, applying strain to the fabric. During a period of flapping in the wind, the fibers in the fabric will be subject to repeated strain, and any slack present or developed in them will be taken up by a rearrangement of the fibers, leading to slack in the fabric as a whole. On pitching the tent again, or adjusting it, this fabric slack will be taken up and the whole process repeated. Thus both at the fiber and the fabric level there is an approximation to cumulative extension cycling. Many other instances occur in the use and processing of textiles.

Cumulative extension cycling is also used as the basis of most fatigue testing of fibers and yarns. It is consequently necessary to appreciate what is happening in order to understand the results of such tests. Booth and Hearle[1] measured values of elastic recovery and then used a computer program to predict the behavior in each successive cycle: they found that, in some circumstances, the predicted extension reached a limiting value while, in others, it increased indefinitely leading to rupture. Assuming a linear relation between elastic recovery and strain, they showed how a limiting extension could arise. Their experiments, being designed to in-

* Present address: University of Manchester, Institute of Science and Technology, Manchester, England.

vestigate fatigue *failure*, were all carried out at high extension levels so that a limiting extension was not found experimentally.

The present paper treats the problem more generally and reports experimental data where a limit is achieved as well as where it is not. In practical use, the achievement of a stable limiting state after a limited number of repeated applications of strain is an important and valuable characteristic in a textile material, while the contrary behavior of a steady approach to ultimate failure is a defect.

THEORY

The Assumed Model

Concentrating on the dependence of cumulative extension cycling on elastic recovery, we take a model with the following simplifying assumptions. The basic features are illustrated in the fiber stress–strain curve, Figure 1.

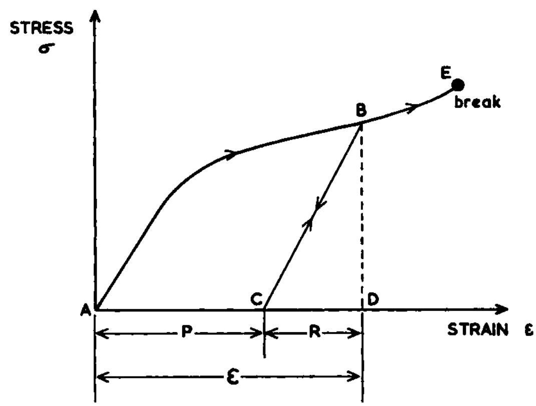


Fig. 1. Idealized stress–strain curve showing total strain ϵ, recovered strain R, and permanent strain P.

(*a*) The stress–strain curve in simple extension is ABE. If a specimen is strained to any point B and allowed to recover to C, it is assumed that on re-straining, the original stress–strain curve will be rejoined at B and then followed towards E. (*b*) It is assumed that on first reaching any strain level, such as B, the elastic recovery r, defined as the ratio of elastic strain R, to total strain ϵ, will be a function only of strain ϵ. In particular, r will be independent of the previous history at lower strain levels. These are the two basic assumptions, but, we can add: (*c*) Repeated application of the same level of strain B does not lead to any change in the elastic recovery value; (*d*) Viscoelastic time-dependent effects are ignored. (*e*) Break occurs at the same point E irrespective of the previous history, thus any true "fatigue" effects are not taken into account.

Behavior in Simple Extension and Load Cycling

We can now note the behavior in simple cycling procedures. Simple extension cycling between fixed limits of imposed strain without removal of slack is shown in Figure 2*a*. Initially the stress–strain curve is followed from A to B; recovery to zero strain goes along BCA; and then re-straining to B reverses the path ACB. The strain level B cannot be exceeded, and the path $BCACB$ is followed in all succeeding cycles. It will be noted that the return path from C to B has been shown here as different from the path from B to C: this, while it is avoided in the simpler model shown in Figure 1, is not incompatible with the basic assumptions.

Simple load cycling, as in Figure 2*b* between the levels A and B, is almost identical, except that there is an immediate reversal at C, without traversing the region of slack fiber back to the original length at A.

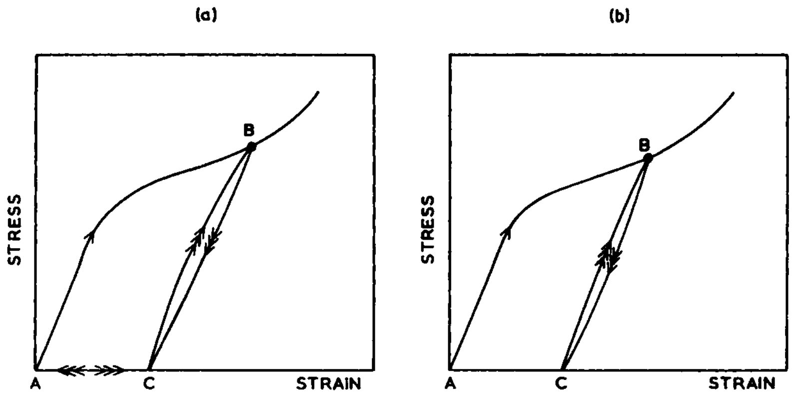


Fig. 2. Behavior of model in (*a*) simple extension cycling and (*b*) load cycling.

Cumulative Extension Cycling

Figure 3 illustrates the behavior in cumulative extension cycling. An imposed strain ϵ_1 is applied to the material and then released; the material has a permanent strain P_1 after this first cycle. The slack P_1 is removed, and then the imposed strain ϵ_1 is again applied. The strain on the material in the second cycle is now $\epsilon_2 = P_1 + \epsilon_1$; after the second cycle the permanent strain is P_2 and this is removed before applying ϵ_1; and so on. Summarizing, we have:

First cycle:

$$\text{Imposed strain} = \epsilon_1$$

$$\text{Total strain} = \epsilon_1$$

$$\text{Permanent strain} = P_1 = (1 - r_1)\epsilon_1 \tag{1}$$

Second cycle:

$$\text{Total strain} = \epsilon_2 = P_1 + \epsilon_1 = (1 - r_1)\epsilon_1 + \epsilon_1 \tag{2}$$

$$\text{Permanent strain} = P_2 = (1 - r_2)\epsilon_2 \tag{3}$$

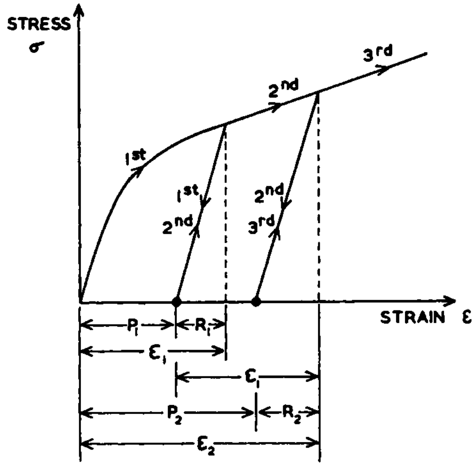


Fig. 3. Cumulative extension cycling.

$(n - 1)$th cycle:

$$\text{Permanent strain} = P_{n-1} = (1 - r_{n-1})\epsilon_{n-1} \tag{4}$$

nth cycle:

$$\text{Total strain} = \epsilon_n = P_{n-1} + \epsilon_1 = (1 - r_{n-1})\epsilon_{n-1} + \epsilon_1 \tag{5}$$

$(n + 1)$th cycle:

$$\text{Total strain} = \epsilon_{n+1} = P_n + \epsilon_1 = (1 - r_n)\epsilon_n + \epsilon_1 \tag{6}$$

The strain will have reached a limiting value when the total strain in successive cycles remains unaltered. That is, when:

$$\epsilon_n = \epsilon_{n+1} \tag{7}$$

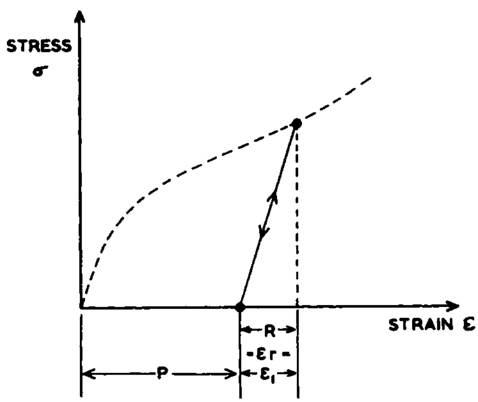


Fig. 4. Limiting condition in cumulative extension cycling.

or

$$\epsilon_n = (1 - r_n)\epsilon_n + \epsilon_1 \tag{8}$$

$$\epsilon_n r_n = \epsilon_1 \tag{9}$$

In general, the condition for the limiting extension is thus:

$$\epsilon r = \epsilon_1 \tag{10}$$

where ϵ_1 is the constant strain imposed in each cycle.

This condition states that at the limit, the strain recovered after a cycle just equals the imposed strain, so that there is no additional straining in the next cycle. This is illustrated in Figure 4.

Application of Theory

If elastic recovery values are known as a function of ϵ, then eqs. (1)–(6) can be used to calculate the total, elastic, and permanent strains in each successive cycle. This is most conveniently done on a computer. In the particular computer program which we used, the elastic recovery values as a function of strain were obtained from experimental data in the following manner: A smooth curve was drawn through the measured data points of elastic recovery factor as a function of strain. A large number of coordinates of this curve were input to the computer. To obtain the elastic recovery values at any required strain between these coordinates, a linear interpolation formula was used. A limiting extension was assumed to have been reached when the strain in five successive cycles differed by less than 1×10^{-8}.

The occurrence, or otherwise, of a limit can be predicted by examination of a comparison of plots of the hyperbolas $\epsilon r = \epsilon_1$ with plots of the experimentally determined relation between r and ϵ. This is illustrated in Figure 5, Booth's[2] experimental values of r for various yarns being used. The

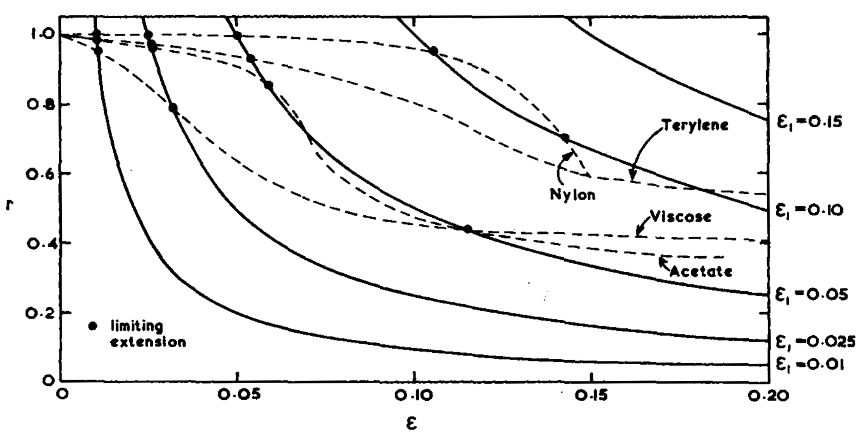
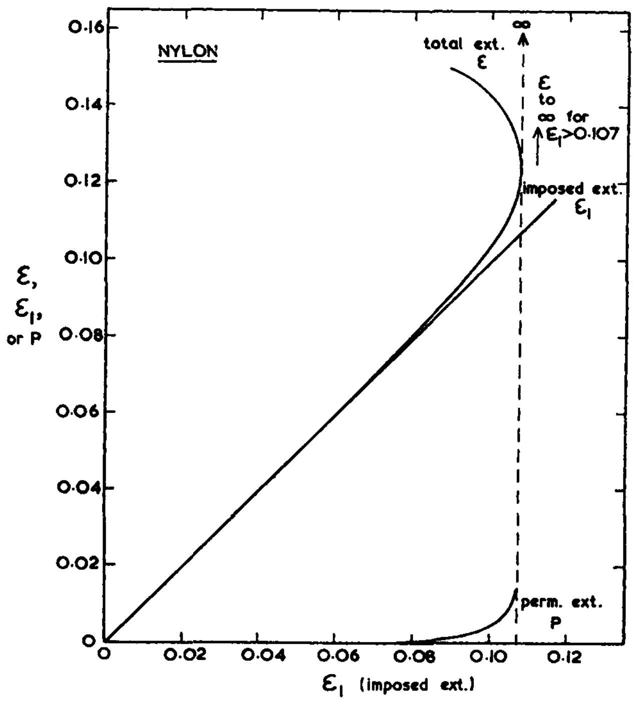


Fig. 5. Plot showing limiting extension values: (——) hyperbolas $\epsilon r = \epsilon_1$; (- -) experimental elastic recovery values.



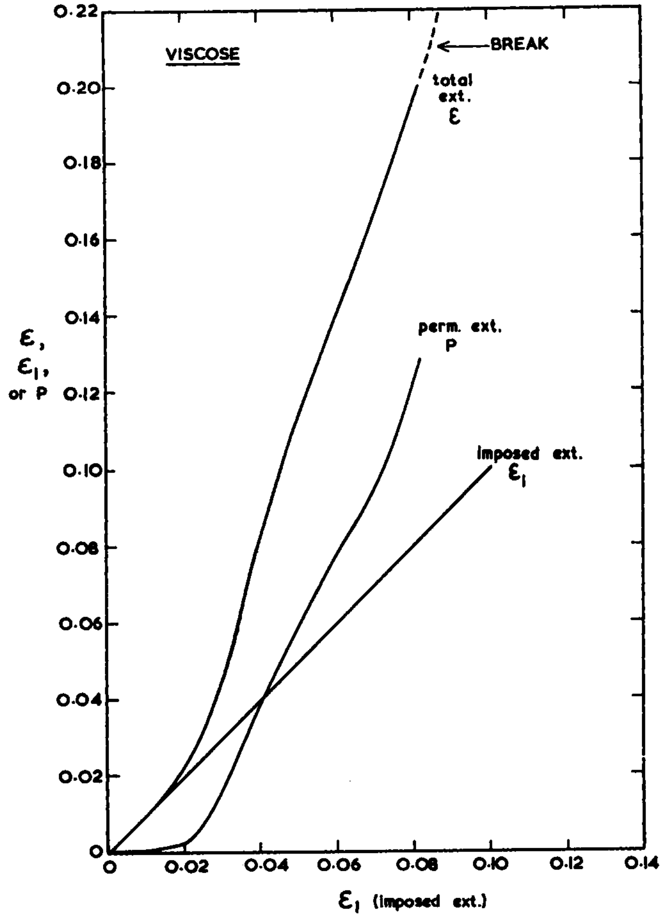
(*a*)

Figure 6. See caption, p. 1955.

limiting extension occurs where the experimental curve crosses the hyperbola for the given imposed extension level ϵ_1. Thus viscose rayon under an imposed strain of 0.025 (2.5%) should achieve a stable limit when the total extension has reached 0.038 (3.8%).

We can therefore expect three different types of behavior during cumulative extension cycling: (*a*) if the limiting extension is less than the breaking extension, the specimen will steadily increase in length until it reaches the stable limiting value; (*b*) if the limiting extension is greater than the breaking extension, the specimen will fail before it reaches the limit; (*c*) there may be no limiting extension, and hence the specimen will extend indefinitely and finally fail by breaking.

The distinction between (*b*) and (*c*) is, in a way, artificial, since both describe a steady increase in extension up to the breaking point. However, looking at Figure 5, we can see that viscose rayon with $\epsilon_1 = 0.1$ (10%) looks like (*b*), since extrapolation beyond the breaking extension clearly leads to a crossing point, whereas nylon with $\epsilon_1 = 0.15$ (15%) looks like (*c*) because the two curves are diverging from one another. It also follows that where, as always happens in practice, there is a distribution of breaking extensions, then the individual specimens in a sample may, for particular values of ϵ_1, be divided between types (*a*) and (*b*); whereas, if type (*c*) occurs, it must apply to all specimens with the same recovery and stress–strain properties.



(*b*)

Fig. 6. Predicted behavior of (*a*) nylon and (*b*) viscose at various levels of imposed strain.

Another important difference is that nylon shows a sharp change of behavior at the imposed extension level where the hyperbola just touches the experimental curve. As shown in Figure 5, this occurs when $\epsilon_1 = 0.107$. For smaller imposed extensions a stable limit is achieved, and even with $\epsilon_1 = 0.107$, the additional permanent extension is small, so that the total strain at the limit is only 0.12. For ϵ_1 values greater than 0.107 there will be no stable limit, and the specimen will increase in length indefinitely. On the other hand, in viscose rayon there will be no abrupt change in behavior; the limiting extension will steadily rise as the imposed extension is increased until eventually it reaches the level of the breaking extension. The behavior of the two materials is compared in Figure 6, which shows how the total limiting extension and the permanent part of the extension vary with the imposed extension.

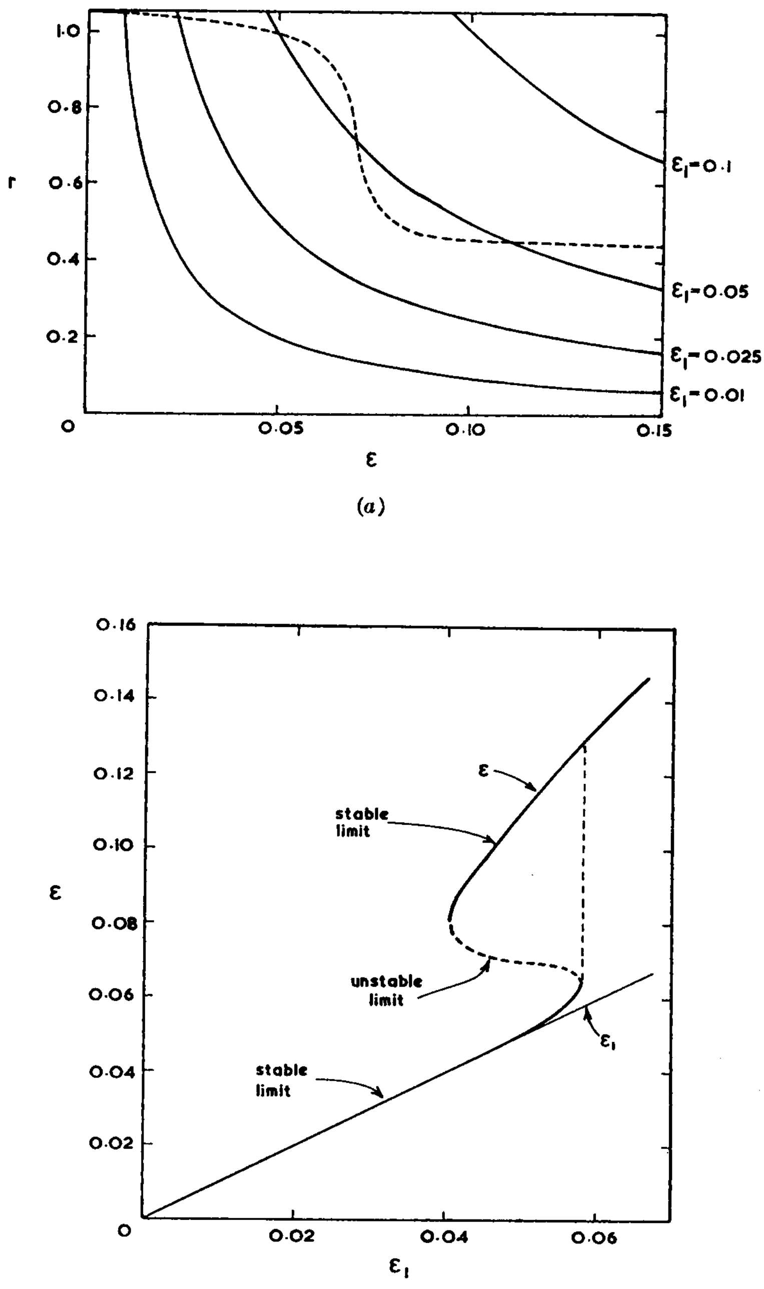


Fig. 7. Plot with (*a*) three crossings of hyperbolas by experimental curve; (*b*) predicted behavior, showing unstable region (below and to right of line) where extension will increase up to limit, and stable region (above and to left of line) where extension will drop back to limit.

In a simple cumulative extension test, it is not, of course, possible to go beyond the limiting extension. If, however, due to an aberration of procedure, a particular cycle did go to a higher level, the specimen would drop back to a stable limit when the correct imposed extension was again applied. A second crossing of the two curves in the opposite direction also satisfies eq. (10) but is unstable, because if the extension became fractionally greater the specimen would be in a region where successive cycles at the given imposed extension level again resulted in a steady increase of length. Thus nylon with $\epsilon_1 = 0.1$ would reach the limiting strain of 0.105, would remain stable as long as the total strain never exceeded 0.143, but would become unstable to an imposed strain of 0.1 if its extension were taken above 0.143. A third crossing would again lead to a stable state, as illustrated in Figure 7. A fourth crossing would be unstable, and so on.

Energy Input Cycling

An alternative cycling procedure is the imposition of a given amount of energy in each cycle. This is perhaps more closely related to what often happens in the practical use of fibers. Figure 8*a* shows that the behavior is rather similar to cumulative extension cycling, since there can be no take-up of the energy until the slack has been removed. With assumptions analogous to those already made, the situation can be analyzed in the following way.

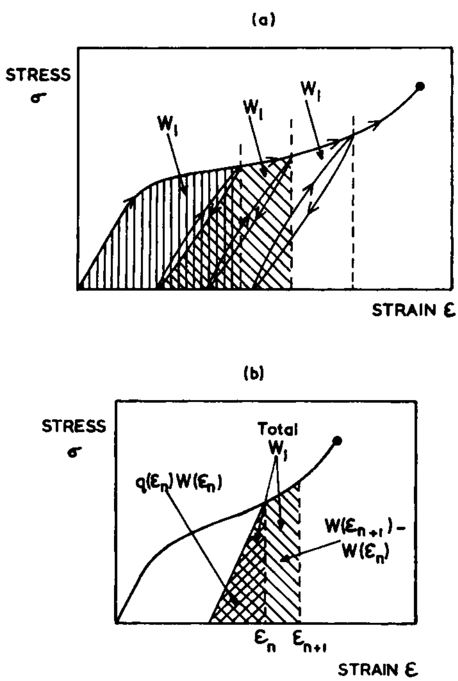


Fig. 8. Energy cycling.

Let W_1 denote the energy imposed in each cycle; $W(\epsilon)$, the work absorbed in extending the specimen on the first occasion from zero strain to the strain ϵ; and $q(\epsilon)$, the work recovery from strain ϵ. Then work recovered in the nth cycle from a strain ϵ_n is $q(\epsilon_n)W(\epsilon_n)$.

Assuming recovery along strictly the same path, as in Figure 8*b*, we see that the strain ϵ_{n+1} in the next cycle must be given by:

$$W_1 = q(\epsilon_n)W(\epsilon_n) + [W(\epsilon_{n+1}) - W(\epsilon_n)]$$

or

$$W(\epsilon_{n+1}) = [1 - q(\epsilon_n)]W(\epsilon_n) + W_1 \qquad (11)$$

This is analogous to eq. (6).

The condition for a limit, namely $W(\epsilon_{n+1}) = W(\epsilon_n)$ will yield:

$$W(\epsilon)q(\epsilon) = W_1 \qquad (12)$$

EXPERIMENTAL METHODS

The experiments needed to check the theory are of two types: (*a*) measurement of elastic recovery as a function of strain; (*b*) measurement of strain developed during cumulative extension cycling.

Elastic Recovery Measurement

Elastic recovery is measured by imposing a strain and removing it, measuring the amount of recovered strain or the amount of permanent elongation (they are complementary) and then imposing strain again in the next cycle. There are two options at this point. In one case, the same sample is taken through successive cycles of increased strain—this is called a "recovery test" and the elastic recovery factor plotted as a function of strain is called the "recovery curve." In the other case, a different sample is used for each level of strain cycling; the elastic recovery as a function of strain is determined from the composite behavior of many samples each at a different strain. In practice it is also known, for instance from the work of Guthrie,[3,4] that elastic recovery values depend on rate of straining and on any dwell times at reversal points.

An Instron tensile tester (constant rate of extension) was used for these measurements. The crosshead speed was chosen for all tests to be 20 in./min., and the chart speed was chosen to be 50 in./min. for maximum resolution. A 10-in. gage length was used for all tests. Lengths of material were cut from the package and allowed to relax for about 1–2 hr. before being tested. The sample was clamped in the top jaw and then clamped in the bottom jaw under a slight tension (<1 g.) exerted by hand to remove crimp. In the case of the recovery test, the sample was given two cycles at each selected strain level. In the other case, the sample was given nineteen cycles at its particular strain. These strain cycles were performed by using the Instron's "extension cycling" procedure. There was no dwell at the reversals.

It was estimated that elastic recovery from 10% extension could be measured with a percentage uncertainty of about 5%. Better accuracy would be achieved at higher strains.

Cumulative Extension Test

In order to perform cumulative extension cycling on the Instron, a special apparatus was developed. The apparatus performs the following sequence of operations each cycle.

The lower jaw assembly is held while the crosshead moves down (imposing the constant amount of strain); then the crosshead reverses, returning to the top extension limit. A special electrical circuit, connected to the Instron, delays the crosshead reversal at the top. During this delay, the lower jaw is released, and its weight removes the slack in the sample. The lower jaw is gripped again in this new lower position, and then the delay ends and the crosshead moves down again beginning another cycle. The change in position of the lower jaw assembly and suspended photocell mask are measured by the change of exposed area of a photocell and the output of the photocell is recorded on a chart recorder. Thus, the amount of permanent strain P_n removed in each cycle is measured by the photocell. From this data, the total strain in the nth cycle is known as a function of n, the number of cycles.

This special apparatus is described in more detail in the Appendix.

In addition to the small errors associated with Instron testing, the following problems were encountered.

The clamping mechanism for the lower jaw assembly is operated by a solenoid. The 8-lb. force exerted by the solenoid is sufficient to prevent any slip by the lower jaw when it is clamped. As the solenoid plunger moves into the clamping position, it moves the lower jaw transversely to the fiber axis. This may at times cause transverse waves in the fiber which might produce some sort of fatigue effect. The solenoid plunger does not, however, move the lower jaw longitudinally to the fiber axis so that the amount of slack removed is not changed during the clamping operation. The delay time can be adjusted so that all the slack can be taken out before the lower jaw is clamped. The inertia of the suspended photocell shade causes it to oscillate longitudinally on its suspension wire when the lower jaw moves to a new position. These oscillations damp out before the cycle is finished so that a measurement of the lower jaw position is not disturbed.

The photocurrent output of the photocell can be made an approximately linear function of the exposed area by masking off part of the photocell surface. A calibrated ruler can be constructed to convert photocell output to slack removed. A Leeds and Northrup Speedomax recording potentiometer was used to record the photocell output. The resolution of the chart has a limit of the width of the pen line. This corresponds to a resolution of 0.005 in. of lower jaw movement. Thus, the measurement of slack removed has an uncertainty of 5%, or less.

RESULTS

Basic Properties

The materials studied were single filaments of acetate rayon, nylon, polyester, and viscose rayon. Except for the nylon, which was obtained as a monofilament, the other fibers were obtained as multifilament yarns

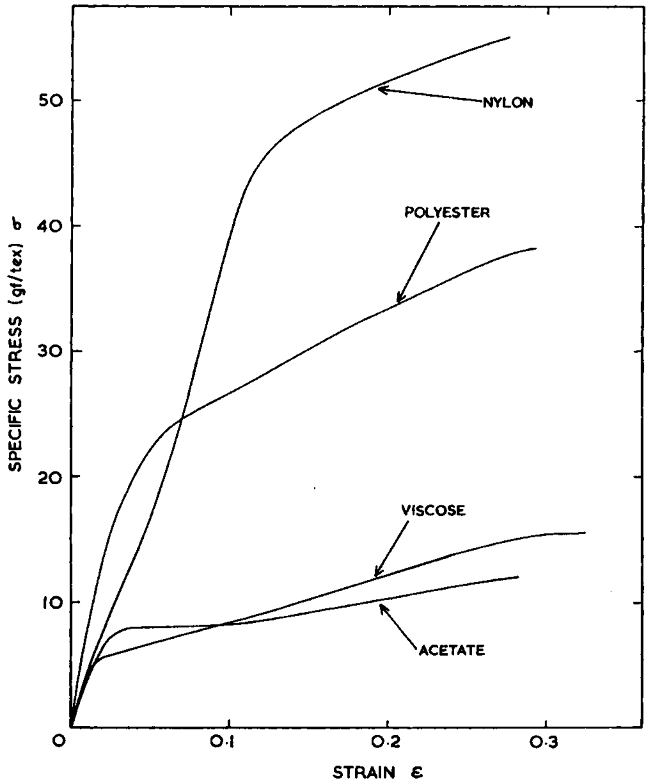


Fig. 9. Stress–strain curves.

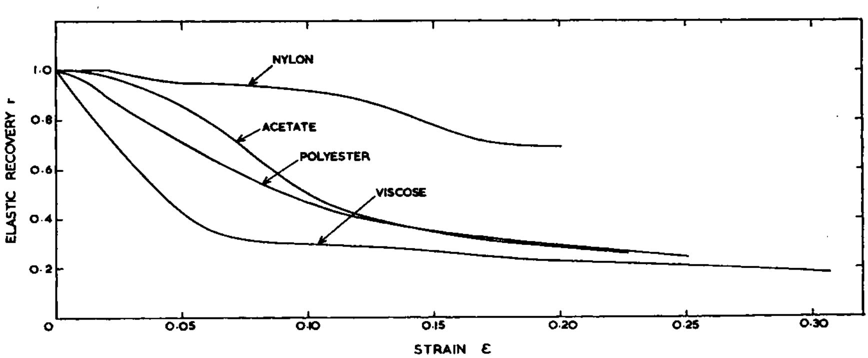


Fig. 10. Elastic recovery curves.

and then separated into single filaments for study. The reason for this use of single filaments from multifilament yarns was that monofilament yarns of approximately 2 tex (18 den.) were not commercially available. Details of the fibers are given in Table I.

TABLE I
Fibers Studied

Type	Brand	Yarn tex/ no. filaments (yarn denier/ no. filaments)	Tex of single filament (denier of single filament)
Acetate	Celanese (900-40-2Z-35W-B)	100/40 (900/40)	2.5 (22.5)
Nylon	duPont (15-1-0-280-SD)	1.67/1 (15/1)	1.67 (15.0)
Polyester	Celanese (40-7-0-6-B)	4.4/7 (40/7)	0.636 (5.72)
Viscose	Enka (900-50-3.2S-BX)	100/50 (900/50)	2.0 (18.0)

Figure 9 is a comparison of the stress–strain behavior of the fibers studied.

Figure 10 compares the recovery curves of the four fibers. The recovery curve (as defined above) is a plot of the elastic recovery factor versus strain measured by increasing the level of imposed strain on the same sample. The elastic recovery curve ends at the breaking strain of the sample.

Simple Extension and Load Cycling

For comparison with the predictions given in Figure 2, Figure 11 shows the behavior of an acetate fiber in simple extension and load cycling. Contrary to the behavior of the model, there is a gradual reduction of peak stress and increase of permanent extension (decrease of elastic recovery) in successive cycles of simple extension cycling; and there is a corresponding

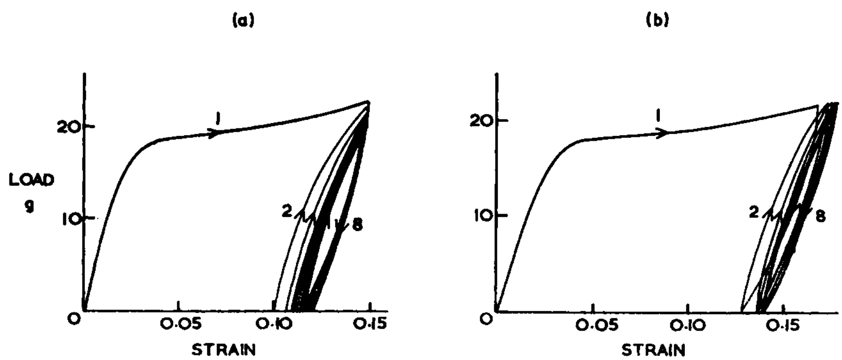


Fig. 11. Acetate fiber (2.5 tex) in (a) simple extension cycling and (b) load cycling.

increase of total and permanent extension in load cycling. These effects correspond to the occurrence of some secondary creep (nonrecoverable time-dependent extension) as the test proceeds.

The simple extension cycling is, of course, the procedure used to obtain elastic recovery values after a number of cycles.

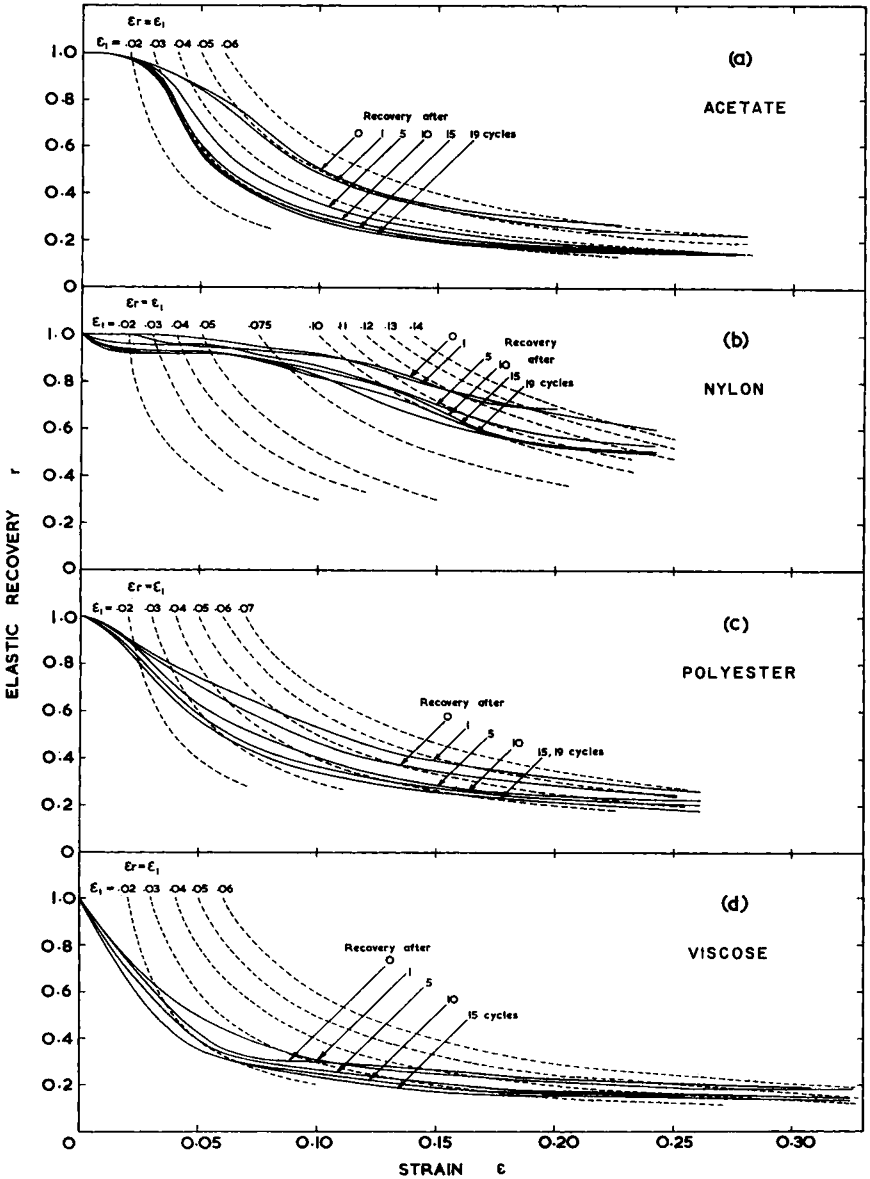


Fig. 12. Elastic recovery curves for different numbers of cycles compared with hyperbolas, $\epsilon r = \epsilon_1$: (*a*) acetate; (*b*) nylon; (*c*) polyester; (*d*) viscose rayon. (Note: zero cycles curve is for elastic recovery from successive extensions in a single recovery test.)

Recovery and Cumulative Extension Tests

Figure 12 shows elastic recovery plotted versus strain for each material for different numbers of cycles at the same extension. Number of cycles = 0 means the recovery curve as defined above. Number of cycles = 5, for example, means that after five extension cycles at a particular strain, the elastic recovery factor was measured; different samples were used for extension cycling at other strains, and the elastic recovery factor vs. strain is a composite picture of all the measurements made after five cycles at various strain levels on the different samples. There is a marked change in the elastic recovery curves for the first few cycles but little change beyond 10 cycles.

The experimentally determined data of Figure 12 on the elastic recovery factor as a function of strain, $r = r(\epsilon)$, were used as input data for the computer simulation of the cumulative extension cycling behavior. As mentioned earlier, a whole series of coordinates of each curve was input to the computer.

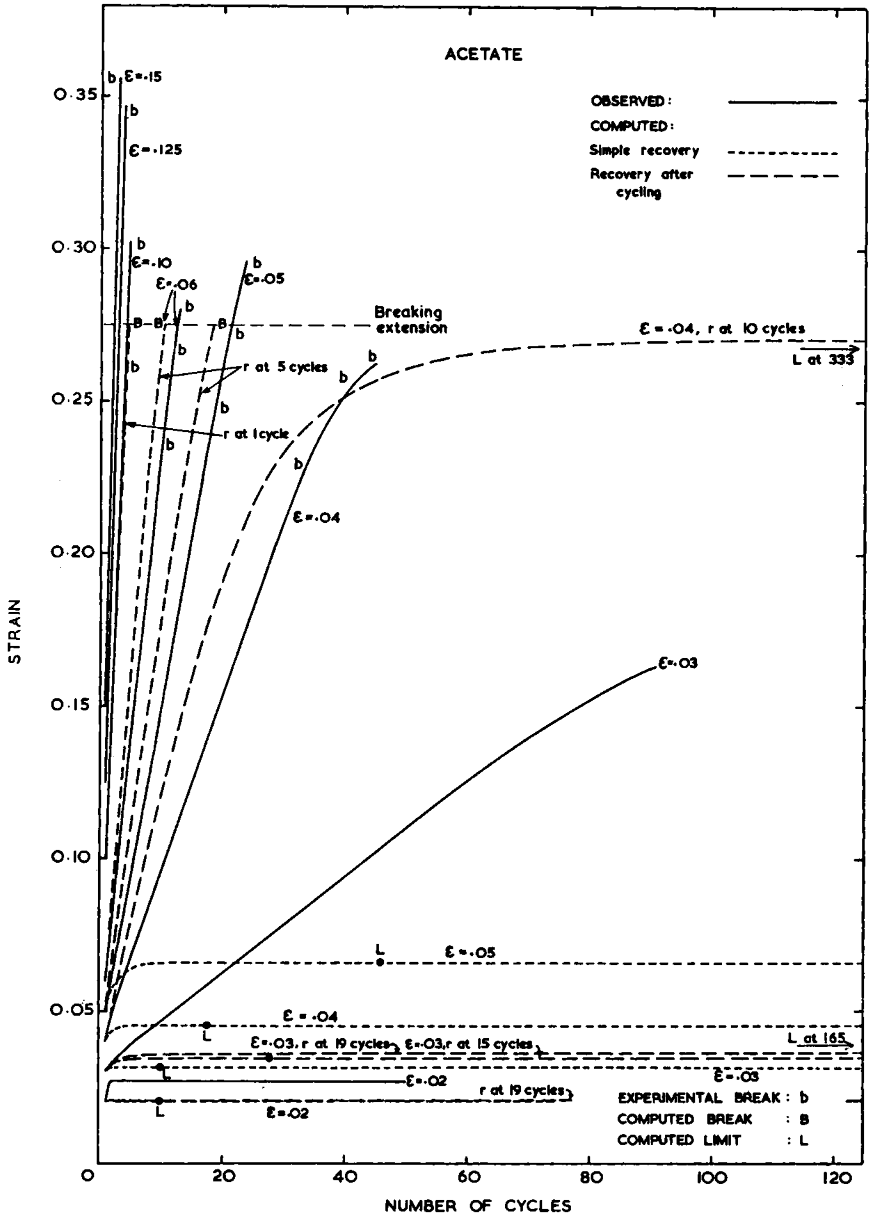
Also included in Figure 12 are curves for the limiting extension condition, $\epsilon r = \epsilon_1$, at various values of the imposed strain, ϵ_1. As discussed earlier, the intersection of the r versus ϵ curve and the $\epsilon r = \epsilon_1$ curve defined the theoretical limiting extension associated with a cumulative extension cycle of strain ϵ_1. The absence of such an intersection means that no limiting extension exists for that value of ϵ_1.

Figure 13 shows the experimental and theoretical behavior of the fibers during cumulative extension cycling. The strain on the sample in the nth cycle, ϵ_n, is plotted versus the number of cycles, n for various values of imposed strain ϵ_1. The solid curve gives the experimental results, and the dashed curves show the best and worst computer-simulated results (using the curves of Fig. 12) for that particular imposed strain. The symbol b means that experimentally the sample broke in the next cycle, B means the computed results show the fiber breaking, and L means the computed results indicate a limiting extension has been reached.

DISCUSSION

The experimental results of Figure 13 can be separated into three parts: (*1*) for small imposed strains, the sample clearly reaches a limiting extension; (*2*) for medium imposed strains, it is not precisely clear based on the number of cycles of these tests whether the sample will reach a limiting extension or will break; (*3*) for large imposed strains, the sample has no limiting extension, but continues to elongate until it breaks.

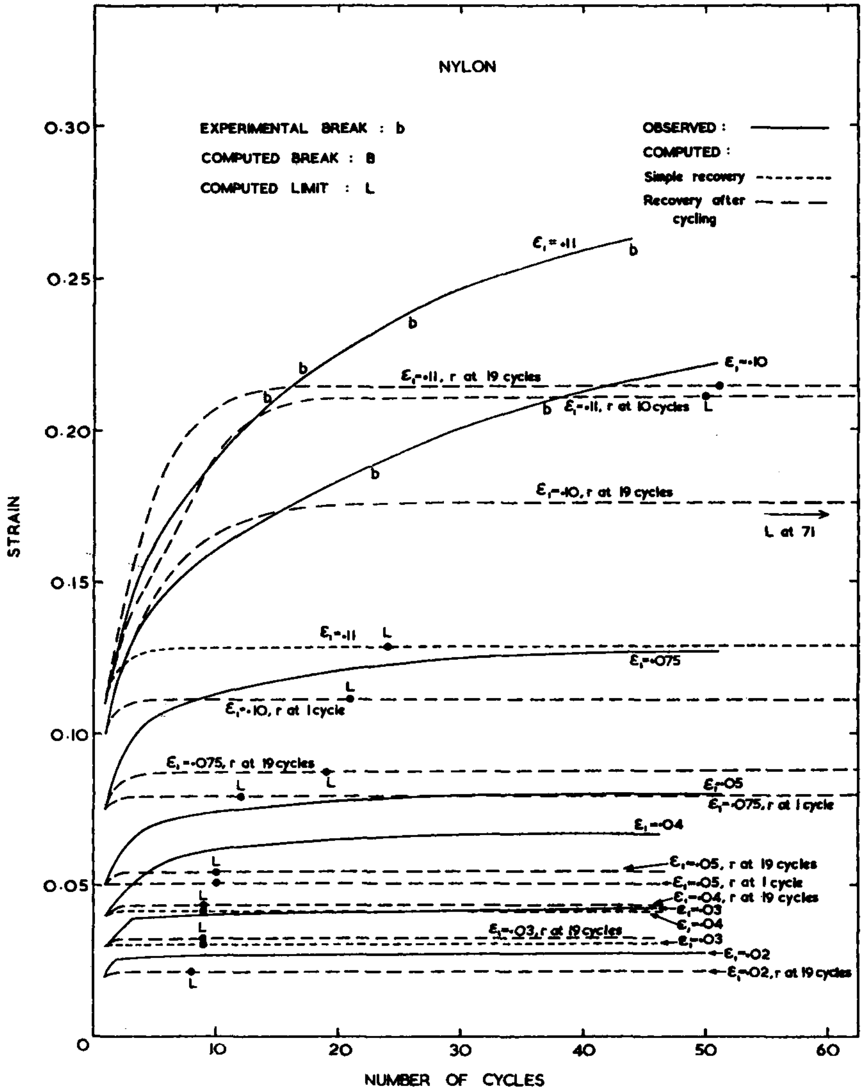
The agreement of the computer-simulated results and the observed results can also be separated into these three parts. (*1*) For small imposed strains, the computed results show a limiting extension which is at a level significantly below the observed limiting extension. The reason for this difference is secondary creep; the idealized model assumed for the computations neglected the effects of secondary creep and its related viscoelastic



(*a*)

Figure 13. See caption, p. 1967.

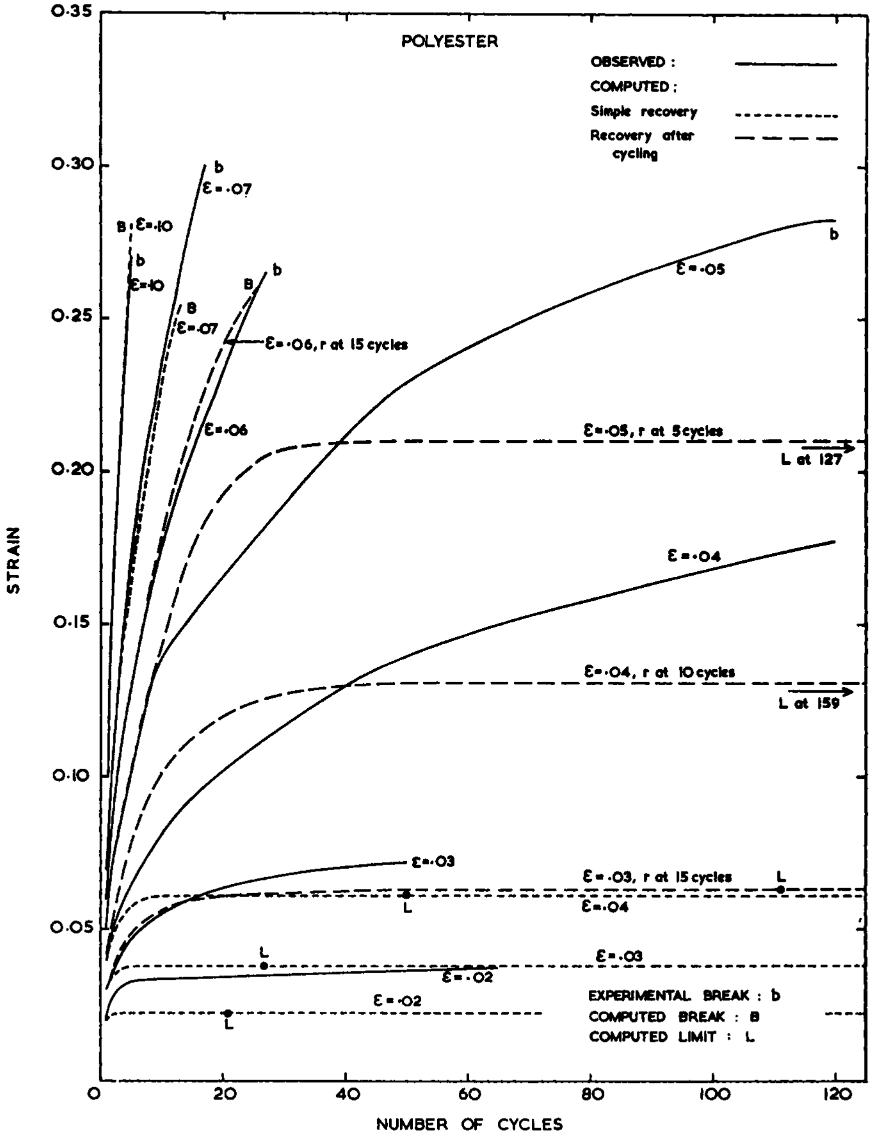
behavior. (*2*) For medium imposed strains, the computed results show a limiting extension, and the observed behavior exhibits a steadily increasing extension such that the fiber breaks or probably breaks in the region of number of cycles beyond those considered in these experiments. Secondary



(*b*)

Figure 13. (*continued*).

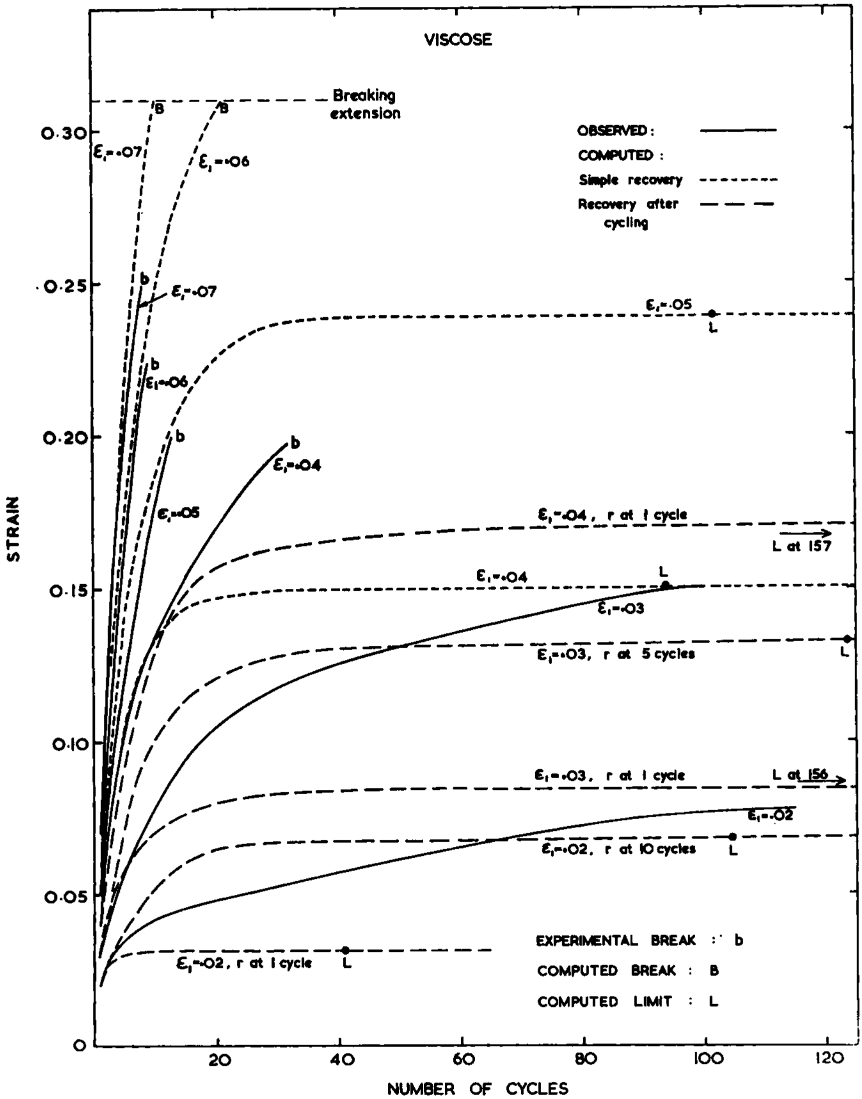
creep and fatigue effects which were not included in the idealized behavior of the model cause the divergence of results between theory and experiment. (*3*) For large imposed strains, the computed results show no limit extension but an increasing elongation until break, and the observed results also show a continuous extension until break. In this region of behavior, the agreement of experiment and theory is good. The elastic recovery as measured in a simple extension test is the dominant effect controlling the behavior.



(c)

Figure 13. (*continued*)

In general, then, it is clear that the experimental behavior is qualitatively similar to the behavior predicted from elastic recovery values, but quantitatively, the experimental results show rather higher values of the limiting total extensions, and change from limiting to continuing extension at a rather lower value of the imposed extension. This can be explained by the addition of continuing secondary creep which is not brought into the elastic recovery measurements.



(*d*)

Fig. 13. Comparison of theoretical and experimental variation of total strain during cumulative extension cycling: (*a*) acetate; (*b*) nylon; (*c*) polyester; (*d*) viscose rayon. On computed curve identification refers to (ϵ_1 value, recovery data).

There is generally closer agreement when elastic recovery values obtained after a number of cycles are used.

The assumptions and approximations made in our idealized model of the material's behavior can be summarized by qualitatively comparing the idealized stress–strain curve and the real one in Figure 14.

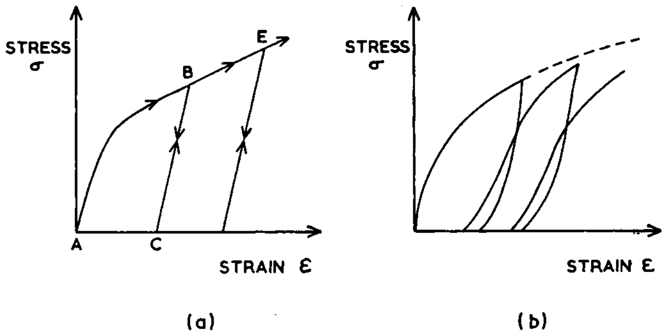


Fig. 14. Stress–strain plots: (*a*) idealized behavior; (*b*) real behavior.

The actual behavior is more complicated than the idealized model because delayed elastic recovery prevents the path *BC* from being retraced upon reloading and because secondary creep shifts peaks like *E* away from the tensile curve toward larger values of strain.

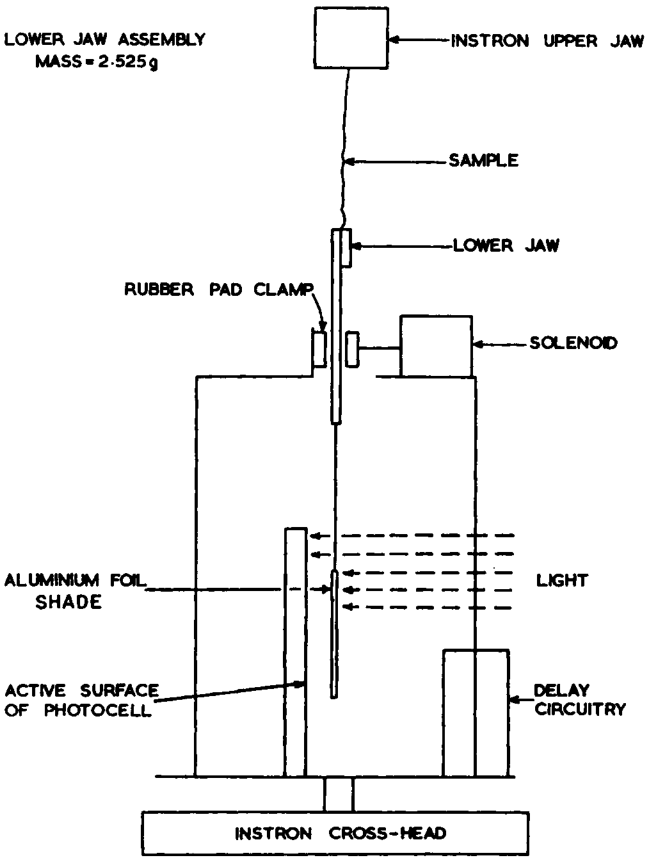


Fig. 15. Cumulative extension cycling apparatus.

The idealized model also assumed no time effects such as the dependence of the elastic recovery on strain rate and cycling frequency. As the strain rate or the frequency of the cycling increases, the elastic recovery factor increases because there is less time in which secondary creep can increase the permanent elongation of the material.

CONCLUSIONS

This research has indicated the extent to which cumulative extension cycling behavior of fibers can be described by the elastic recovery of the material. Any effects of viscoelasticity and fatigue will be superimposed on this. The results show that for small imposed strains, secondary creep

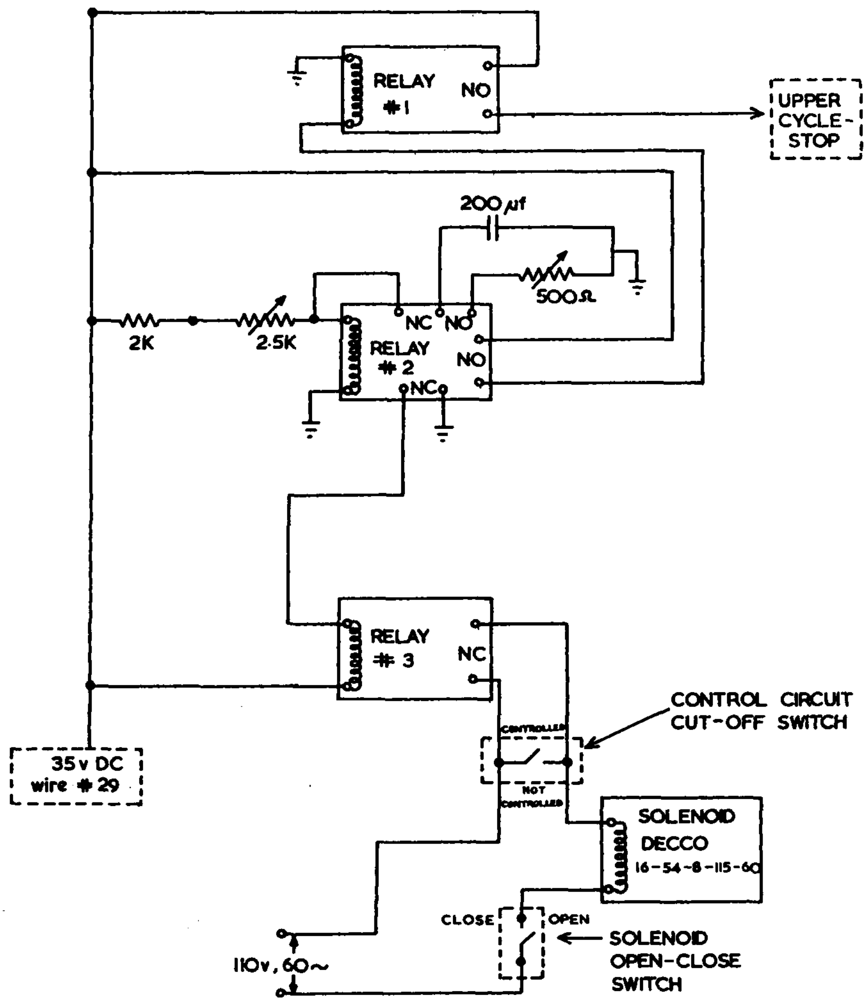


Fig. 16. Delay circuit for Instron crosshead reversal.

increases the observed value of the limiting extension above the limiting extension predicted by the elastic recovery model. For medium imposed strains, a transition region of sorts occurs because the actual behavior shows increasing elongation until break, whereas the model behavior indicates a

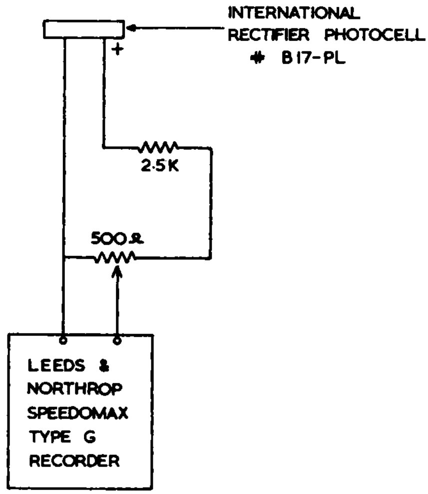


Fig. 17. Photocell circuit.

limiting extension should occur. This means that the effects of viscoelasticity, like secondary creep and time dependence, are important in this region of imposed strain. For large imposed strains, the effects of elastic recovery are dominant because the model and actual behaviors were in agreement.

APPENDIX

The essential features of the cumulative extension cycling apparatus are shown in Figures 15–17.

We wish to express our gratitude to Professor Stanley Backer for his suggestions and support, and for allowing the use of the Fibers and Polymers Division facilities at Massachusetts Institute of Technology.

This work was done, in part, at the Computation Center at the Massachusetts Institute of Technology.

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Résumé

Le comportement dû à l'extension cumulative cylique est le résultat de la combinaison des effets du recouvrement élastique, de la viscoelasticité et de la fatigue. Le but de la présente recherche était d'examinet l'aspect du recouvrement élastique de ce comportement. Un comportement modèle idéalisé en vue d'inclure uniquement le recouvrement élastique est proposé et un programme est proposé pour représenter l'extension cumulative au cours du comportement basé sur ce modèle idéalisé. Les essais sont effe-ctués avec un appareil qui permet d'éliminer les déchets des échantillons après chaque cycle. La comparaison des résultats expérimentaux et calculés fournit une compréhension meilleure des aspects du recouvrement élastique de ce comportement de l'extension cumulative.

Zusammenfassung

Das Kumulativverhalten bei Dehnungscyclen ist durch den kombinierten Einfluss von elastischer Erholung, Viskoelastizität und Ermüdung bedingt. In der vorliegenden Arbeit wird der Einfluss der elastischen Erholung auf das Verhalten untersucht. Ein idealisiertes Verhaltens modell mit alleiniger elastischer Erholung wurde aufgestellt und ein Computerprogramm zur Simulierung des Kumulativverhaltens bei Dehnungscyclen mit diesen idealisierten Modell geschrieben. Tests wurden mit einem Apparat ausgeführt der das lose Ende der Probe nach jedem Cyclus entfernte. Ein Vergleich der Versuchs- und der Computerergebnisse führte zu einem besseren Verständnis des Einflusses der elastischen Erholung auf das Kumulativverhalten bei Dehnungscyclen.

Received July 6, 1966
Prod. No. 1436