A Study of Inverse Relaxation in Some Textile Fibers

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Synopsis

This article discusses the phenomenon of inverse relaxation in some textile fibers, namely cotton, ramie, wool, polyester, and viscose. If an extended viscoelastic specimen is allowed to recover a part of the deformation given to it, such that its tension has not become zero, the stress in it tends to increase. This phenomenon is termed as "inverse relaxation." This property is measured in terms of an index referred to as the inverse relaxation index. The values of this index at various extension and retraction levels for the above materials are presented and discussed in this article.

INTRODUCTION

The stress developed in a specimen constrained to remain in the extended state is known to decay with time, the process being referred to as "stress–relaxation." On the other hand, if an extended specimen is allowed to recover a part of the deformation given to it and is held at a length higher than what it would have assumed if allowed to retract fully, the stress in it shows an increase. This phenomenon is termed as "inverse relaxation" (IR). A survey of the literature shows that information on inverse relaxation is very meager while, on the other hand, voluminous data are available on other time-dependent mechanical properties like stress–relaxation, creep, creep recovery, etc. The only workers to carry out a study of IR have been Vitkauskas and Matukonis,[1-3] who studied this phenomenon occurring in rayon and capron fibers. The present authors in recent articles have reported on the occurrence of IR in cotton[4] and other spun yarns.[5] The present article discusses IR data obtained on different fibers like cotton, viscose, polyester, ramie, and wool.

EXPERIMENTAL

Materials

The fibers studied were cotton (variety: "Varalaxmi"), 2-den viscose staple, purified ramie, 1.5-den polyester staple, and coarse Indian wool (variety: "Rampur Bushier").

Determination of Inverse Relaxation

The Instron tensile tester was used for the determination of IR. The experiment was comprised of stretching the specimen, allowing it to retract partially, and then observing the stress buildup over a period of time.

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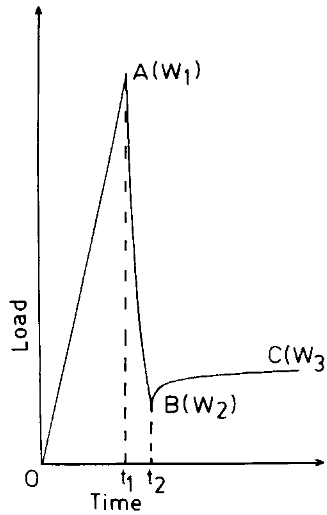

Fig. 1. A typical load vs. time curve in an inverse relaxation experiment.

On the basis of the breaking extension value, different stretch levels were chosen for each fiber type. For each level of stretch, a few retraction levels were also selected.

A typical load vs. time curve in an IR experiment is shown in Figure 1. OA corresponds to the elongation et_1 of the specimen in time t_1 (e is the rate of extension of the specimen). At this instant, the load on the fiber is W_1. During the interval t_1 to t_2, the material is allowed to retract through $e(t_2 - t_1)$. This is represented by AB. The load on the fiber has now reduced to W_2. If the specimen is constrained to remain at the net extension of $e(2t_1 - t_2)$, the tension in the specimen begins to increase, signifying the onset of IR. The stress rises fast in the beginning but later tends to level off. When the time is t_3, the load in the specimen is W_3. The interval $(t_3 - t_2)$ during which IR was recorded was kept arbitrarily at 200 s, since the increase in load thereafter was found to be negligible. The ratio $[(W_3 - W_2)/W_1] \times 100$ has been referred to as the inverse relaxation index (IR index).

Estimation of Recovery Parameters

The elastic recovery parameters, namely immediate elastic recovery (IER), delayed recovery (DR), and permanent set (PS), were estimated at selected extension levels by employing ASTM procedure[6] with minor modifications. Figure 2 depicts the load–extension curve in a recovery test carried out on the Instron. Point A corresponds to zero extension. The point A is so chosen that the fiber would have remained just taut had the crimps on the fiber been absent. This load at A was equal to about 1 g/tax. The fiber was then extended up to a predetermined level B and immediately retracted to the origin via point F on the load line AE. After allowing the fiber to relax for 200 s, the fiber was taken through the second cycle of loading and unloading which is shown by the curve DGHI. If BE is perpendicular to the load line AE, then AE denotes the total extension, FE is termed as immediate elastic

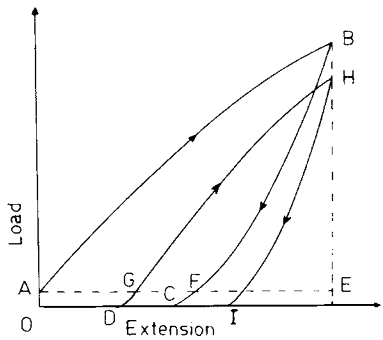

Fig. 2. Load–extension curve in a recovery test for the determination of recovery parameters.

TABLE I
Inverse Relaxation for Cotton Fibers[a]

4% Ext		5% Ext		6% Ext	
Retraction (%)	IR Index	Retraction (%)	IR Index	Retraction (%)	IR Index
0.00	−22.12	0.00	−22.55	0.00	−21.00
1.00	5.22	1.00	6.58	1.00	5.87
2.00	4.43	2.00	4.93	2.00	6.80

[a]Avg br load = 4.2 g; avg br ext = 8.0%; gauge length = 1.00 cm

TABLE II
Inverse Relaxation for Viscose Staple Fiber (2D)[a]

8% Ext		10% Ext		12% Ext	
Retraction (%)	IR Index	Retraction (%)	IR Index	Retraction (%)	IR Index
0.00	−37.39	0.00	−36.42	0.00	−34.32
1.00[b]	−2.22	1.00[b]	−2.34	1.00[b]	−3.66
2.00	9.33	2.00	9.75	2.00	6.75
3.00	8.41	3.00	11.57	3.00	9.72
4.00	3.89	4.00	4.45	4.00	8.54
				5.00	0.49

[a]Avg br load = 3.94 g; avg br ext = 14.97%; gauge length = 1.00 cm.
[b]Shows transition zone.

recovery (IER), GF as delayed recovery (DR) after 200 s, and AG is the permanent set (PS). The load line AE was selected for length measurements since it gives unambiguous values of length and it also takes care of the crimp in the fiber.

RESULTS AND DISCUSSION

The results of IR determination on various fibers are summarized in Tables I–V. The extension and retraction levels indicated in the tables are the nominal values based on the gauge length of 1 cm. Since, for all samples

TABLE III
Inverse Relaxation for Ramie Fibers[a]

3% Ext		4% Ext	
Retraction (%)	IR Index	Retraction (%)	IR Index
0.00	−23.53	0.00	−18.46
1.00	+0.23	1.00	0.27
		2.00	3.00

[a]Avg br load = 38.3 g; avg br ext = 5.37%; gauge length = 1.00 cm.

TABLE IV
Inverse Relaxation for Polyester Staple Fibers[a]

10% Ext		15% Ext		20% Ext	
Retraction (%)	IR Index	Retraction (%)	IR Index	Retraction (%)	IR Index
0.00	−32.67	0.00	−28.69	0.00	−27.95
1.00[b]	2.06	1.00[b]	−0.23	1.00[b]	0.80
2.00	9.06	2.00	5.38	2.00	5.12
3.00	11.85	3.00	8.38	4.00	7.87
4.00	11.77	4.00	9.75	6.00	8.38
5.00	6.34	5.00	10.95	8.00	3.29
6.00	1.36	7.00	0.82	—	—

[a]Avg br load = 9.05 g; avg br ext = 27.89%; gauge length = 1.00 cm.
[b]Shows transition zone.

TABLE V
Inverse Relaxation for Wool (Rampur Bushier) Fiber[a]

30% Ext		40% Ext	
Retraction (%)	IR Index	Retraction (%)	IR Index
0	−35.95	0	−38.79
1.00	−15.27	2.00	−19.46
2.00[b]	−5.14	4.00[b]	−4.40
3.00[b]	+0.02	6.00[b]	5.34
4.00[b]	6.07	8.00[b]	14.96
6.00	11.26	10.00	18.13
8.00	19.62	14.00	17.62
10.00	21.96	16.00	18.99
12.00	24.80	18.00	13.49
14.00	20.87	20.00	10.54
16.00	18.06	22.00	6.78
18.00	15.17	24.00	0.00
19.00	11.77	—	—
20.00	0.00		

[a]Avg br load = 27.3 g; avg br ext = 50.75%; gauge length = 1.00 cm.
[b]Shows transition zone.

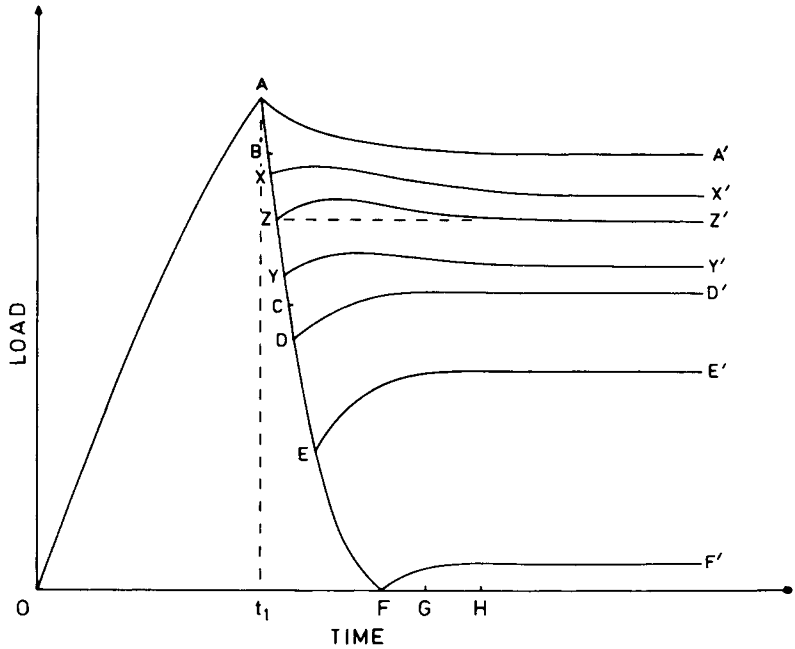

Fig. 3. Load vs. time curve in an inverse relaxation experiment showing load behavior of a fiber corresponding to different levels of retraction.

except wool, plastic tabs were used for mounting on the Instron tests, the actual value of gauge length and hence of extension levels are marginally different from those indicated. But these deviations do not hamper the general conclusions drawn from the results.

The variation of IR index, in fibers under study, with various retraction levels at any given extension follows the same trend as that observed in yarns reported earlier.[5] As retraction level is increased, the IR index also increases from an initially negative value to maximum (positive) value and then decreases to zero. The behavior of fibers at different levels of extension and retraction can be understood with reference to Figure 3 which like Figure 1 gives the load time curve of a fiber specimen. For a given extension corresponding to OA (i.e., equal to extension $e \times t_1$), three phenomena would occur, depending on the retraction permitted. If the specimen is allowed to retract completely, the load–time curve reaches the point H at a time $2t$, along ABCDEFGH. If, on the other hand, no retraction is allowed at all and the specimen is held at the point A, stress–relaxation alone would occur (AA′), giving a negative value for the IR index. For small retraction levels, i.e., between A and B, also stress–relaxation alone would result. Thus the IR index at low retraction levels remains negative. However, when the retraction is increased to a level between B and C, both inverse relaxation and stress–relaxation processes would operate. The load would increase initially for about 5–15 s, signifying the predominance of IR, and thereafter tend to decrease (XX′ and YY′) under the strong influence of the relaxation process. The part BC of the retraction curve is a transition zone in which both the phenomena would operate. In this zone, IR index will emerge from negative to positive side passing through a zero value (ZZ′). Beyond C, only IR would be observed. In this zone, as retraction level is increased, the IR index also increases, reaches a maximum value, and later tends to decrease to zero (curves DD′, EE′, and FF′). The portion G to H corresponds to a permanent set zone for the given stretch. For a retraction level which lies between G and H, there is no inverse relaxation (the IR index is zero). Though load on the specimen becomes zero for the retraction levels lying between F and G, still the specimen exhibits inverse relaxation. Here, when the retraction is stopped the specimen is in the slack condition. But over a period of time the specimen becomes taut showing development of some load.

In wool fibers all the above-mentioned stages are observed whereas with other fibers some stages were not quite discernible. This is due to the fact that the least count of the scale indicating the cross head position in the Instron is 0.01 cm (i.e., 1% of 1 cm gauge length). Retraction levels cannot therefore be adjusted with an accuracy better than 1% of the gauge length. Because of this instrumental limitation, it has not been possible to study IR phenomena at a large number of close retraction levels.

In the case of polyester and viscose fibers we could observe stress–relaxation only at zero retraction. This is immediately followed by the transition zone. On account of the instrumental limitation noted above, it has not been possible to record the intermediate phase of gradual decrease in the stress–relaxation. Beyond the transition zone, we can observe all the other stages.

Cotton and ramie have very low average breaking extensions (5.4% for ramie and 7.5% for cotton). Only three retraction levels could be chosen for these fibers at a given extension level. From Tables I and III it is clear that only three phases are observable, namely stress–relaxation at zero retraction, IR, and finally the latter becoming zero.

As explained in the earlier publications,[4,5] IR is a time-dependent phenomenon in the domain of the viscoelasticity depending mainly on the delayed recovery mechanism. In general, we can therefore expect higher IR index value for a material having higher delayed recovery (DR) value. As can be seen from Table VI, wool has the highest DR among the fibers studied. Hence the IR index maximum must be higher for wool than for any other fiber under study. This is found to be true experimentally. Again for a given material itself, a higher DR value for a given extension amounts to higher maximum IR index. For example, in the case of wool fibers the DR at 30% extension is higher than that at 40% extension level. This is reflected in the maximum IR index, which is 24.80 at 30% extension and 18.99 at 40% extension.

A similar trend is observed in polyester fibers also. The DR goes on decreasing with increasing extension and the maximum IR index also goes on decreasing with increasing extension. In the case of viscose, though DR is more at 8% extension level than at 10% and 12% extension levels, IR maximum at 8% (9.33) is less than those for 10 and 12% (9.75 and 9.72, respectively). As can be seen from Table II, the IR index values at 2 and 3% retraction levels for 8% extension are nearly the same. Hence the actual IR index maximum must be lying at a retraction level in between 2 and 3% and the IR index maximum value at this retraction level would be more than what is obtained in the present case. Due to instrumental limitation, as pointed out earlier,

TABLE VI
Recovery Values of Fibers

Fiber	Ext (%)	IER (%)	DR (%)	PS (%)
Polyester	10	38.61	19.14	42.25
	15	36.00	11.80	52.20
	20	33.00	10.40	56.60
Cotton	4	40.88	14.39	44.73
	5	35.98	13.86	50.16
	6	35.39	9.68	54.93
Viscose staple	8	37.50	15.70	46.80
(2D)	10	37.70	9.60	52.70
	12	34.40	9.70	55.90
Wool	30	35.11	31.00	33.89
	40	34.14	27.45	38.41
Ramie	3	51.72	5.60	42.68
	4	51.09	5.74	43.17

retraction levels between 2 and 3% could not be studied. The comparison of maximum IR index of cotton and ramie cannot be done for the same reason.

Summing up the results obtained, it may be stated that the phenomenon of inverse relaxation can be observed in any viscoelastic material whether it is in the form of fiber or yarn. For any given extension depending upon the retraction level, either stress–relaxation or inverse relaxation or a combination of both would be observed. The IR index maximum depends upon the delayed recovery value for the material at that extension; the higher the DR value the higher is the IR index maximum.

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