Dynamic Compression Mechanical Properties of Fiber Masses with a Rheovibron Viscoelastometer

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Synopsis

The Rheovibron viscoelastometer is useful for obtaining dynamic tensile, shear, and bending mechanical properties of films and fibers over a wide temperature range. In recent years a modification that makes measurement on materials in a liquid or gas medium possible has been reported. A new compression grip and procedure were used for measuring dynamic mechanical properties of a fiber mass in the compression mode using the Rheovibron instrument. The dynamic compression properties on nylon, polyester, and acrylic fibers are presented.

INTRODUCTION

The Rheovibron viscoelastometer (Toyo measuring instrument) is useful for obtaining dynamic tensile mechanical properties of films and fibers over a wide temperature range of −160 to 250°C in an atmosphere at 0% relative humidity.[1] In recent years a modification which makes possible measurement on materials in the shear and bending mode has been reported.[2,3] However, no studies exist that show the measurement of dynamic compression mechanical properties of fiber assemblies using the Rheovibron instrument. In this report a new method for investigating dynamic compression mechanical properties of materials and fiber masses is presented which shows the effects of fiber crimp on dynamic compression properties of polyester, nylon, and acrylic fibers.

EXPERIMENTAL

The Rheovibron applies a sinusoidal tensile strain to one end of a sample and measures the stress output at the other end. The instrument operates at frequencies of 3.5, 11.0, 35.0, and 110 Hz. Two transducers are used to read directly the absolute value of the dynamic complex modulus $|E^*|$, the ratio of maximum stress amplitude to maximum strain amplitude, and the phase angle δ between stress and strain. From these two quantities, the real part E' (dynamic modulus) and the imaginary part E'' (loss modulus) of the complex dynamic tensile modulus E^* can be calculated.

The principles of this direct reading method and instrument are described in detail by Takayanagi.[1] In order to measure the dynamic properties in the compression mode using a Rheovibron viscoelastometer, it was necessary to develop the compression grips to permit characterization of viscoelastic materials in dynamic compression. The compression grip is shown in Figure 1. A small fiber mass or block of specimen is installed in the grip as seen in Figure 1. The compression grips consist of one sample mounting unit and clamp with 15-

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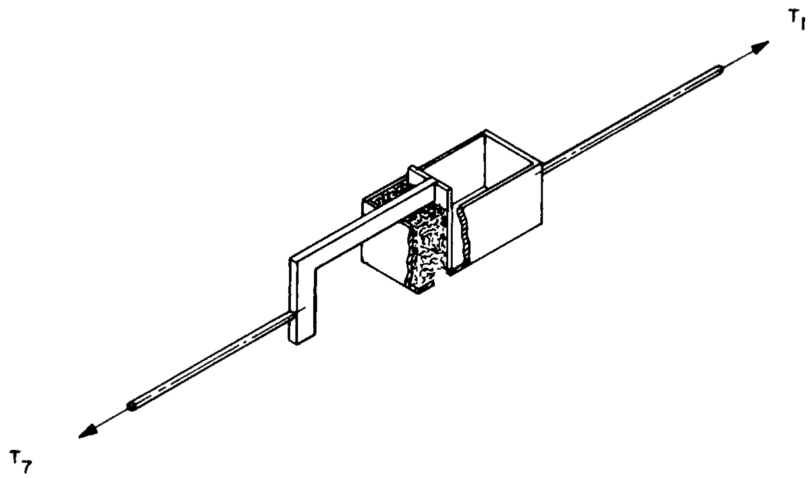

Fig. 1. The compression grip.

cm-long rods; the weight of the grips is 13.2 g. The tensile clamp is replaced by these compression grips at the connector of T_1 and T_7 of the strain gage. A ball-shaped sample of small fiber mass, about 1 cm in diameter, is prepared from a large mass of fibers. The weight of the small fiber mass should be controlled at about 55 ± 2 mg. This is installed in the box (0.7 × 1.70 × 0.7 cm) of sample grip without exeess pressure.

The operating procedure for dynamic compression testing with the Rheovibron is as follows:

With the tan δ range and amplitude factor switches set at 30:

(1) Set the main selector switch to stress (T_1) gauge position.

(2) Turn the handle of the slider of the driving section and apply the initial compression, about 5 g, to the sample. In case of fiber mass, the weight should be about 55 mg. Measure the dimension of the sample.

(3) Set the main selector switch to the "Amp F" position and turn the tan δ meter switch to 40 and the amplitude factor switch to 30.

(4) Adjust "Amplitude Adjust" for full scale indication on the tan δ meter.

(5) Set the main selector switch to the "Dyne F" position.

(6) Adjust the "Phase Adjust" control for the correct Lissajou pattern on the oscilloscope (straight line at approximately a 45° angle to horizontal).

(7) Adjust the "Dynamic Force" potentiometer for full scale indication on tan δ meter.

(8) Turn the main selector switch to "tan δ" position and read tan δ.

(9) Turn the tan δ meter switch to 30 and the amplitude factor switch to 30. Set the main selector switch to stress (T_1) gauge position and read stress.

In order to calculate the dynamic compression modulus (E'_c), the following equation has been derived:

$$E'_c = \frac{2}{AD} \times 10^9 \times \frac{L}{S} \text{ dyn/cm}^2$$

where E'_c = dynamic compression modulus in dyn/cm^2; A = amplitude factor;

TABLE I
Dynamic Compression Mechanical Properties of Fiber Masses[a] (11 Hz, 22°C, 65% RH[b])

Sample	Loss tangent $\tan \delta_c$	Compression: Dynamic modulus E_c' (dyn/cm²)	Compression: Loss modulus E_c'' (dyn/cm²)	External friction $\Delta\delta$
Ultron (Nylon carpet yarn, type 1591)	0.165	9.03×10^5	1.81×10^5	0.151
Polyester	0.24	9.70×10^5	2.33×10^5	0.217
Acrilan Fiber (B-99)	0.32	7.35×10^5	2.36×10^5	0.257
Cotton	0.13	9.66×10^5	1.26×10^5	0.058

[a] Values average of 10 tests.
[b] RH = relative humidity.

TABLE II
Dynamic Tensile Mechanical Properties of Yarns (11 Hz, 22°C, 65% RH)

Sample	Loss tangent $\tan \delta$	Tensile: Dynamic modulus E' (dyn/cm²)	Tensile: Loss modulus E'' (dyn/cm²)
Ultron carpet yarn, type 1591	0.014	1.02×10^{10}	1.43×10^8
Polyester	0.023	8.52×10^{10}	1.96×10^9
Acrilan Fiber (B-99)	0.062	4.71×10^{10}	2.92×10^9
Cotton	0.072	2.57×10^9	1.85×10^8

[a] Values average of 10 tests.
[b] RH = relative humidity.

D = the value of dynamic force dial; L = length of sample; and S = cross section.

By knowing the dynamic compression modulus (E_c') and $\tan \delta$ value, the dynamic compression loss modulus (E_c'') can be determined from the following relationship:

$$E_c'' = \tan \delta (E_c') \text{ dyn/cm}^2$$

A number of nylon carpet yarns and polyester and acrylic fiber masses about 0.6×0.4 cm and 0.4 cm thick were prepared. Dynamic measurements were made at 11 Hz with strain amplitude about 0.4–0.6%. Samples were heated at 1°C/min in a nitrogen atmosphere and measurements of the compression modulus E_c' and damping factor $\tan \delta$ were made at 5 or 10°C increments. Samples were allowed to equilibrate at temperature for 10 min before measurements were made.

RESULTS AND DISCUSSION

The dynamic compression modulus (E_c') along with the loss tangent ($\tan \delta$) and the loss compression modulus of fiber masses (Ultron* nylon carpet yarn, and polyester, acrylic, and cotton fibers) are shown in Table I. The dynamic tensile mechanical properties of constituent yarns of these fiber masses are shown

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TABLE III
Dynamic Compression Mechanical Properties (E', E'', Tan δ)[a]

Temp., °C	Tan δ	Compression E' (dyn/cm^2)	Compression E'' (dyn/cm^2)
22	0.165	1.99×10^6	3.29×10^5
30	0.155	1.94	3.02
42	0.160	1.86	2.98
54	0.160	1.64	2.63
65	0.170	1.53	2.60
75	0.180	1.43	2.58
85	0.185	1.34	2.48
95	0.190	1.30	2.47
105	0.186	1.27	2.35
115	0.170	1.25	2.13
124	0.150	1.23	1.85
134	0.115	1.13	1.30
143	0.089	0.91	0.81
153	0.083	0.86	0.71
161	0.068	0.77	0.52

[a] Sample: Ultron type 1591, 0% RH.

in Table II. The values in the tables are the average of 10 tests. The precision of the data is ±3%.

The loss tangents of the fiber masses were higher than those of constituent yarns. This additional energy dissipation of yarn is caused by fiber-to-fiber friction.[4] The loss tangent (internal friction) gives the amount of energy dissi-

TABLE IV
Dynamic Tensile Mechanical Properties (E', E'', Tan δ)[a]

Temp., °C	Tan δ	Tensile E' (dyn/cm^2)	Tensile E'' (dyn/cm^2)
27	0.014	1.02×10^{10}	1.42×10^8
35	0.011	1.02	1.12
44	0.010	0.99	0.99
52	0.013	0.96	1.25
60	0.017	0.94	1.61
66	0.028	0.92	2.58
71	0.042	0.91	3.83
76	0.051	0.88	4.51
80	0.057	0.82	4.86
85	0.062	0.83	5.15
89	0.077	0.75	5.79
93	0.089	0.70	6.23
96	0.091	0.65	5.98
100	0.097	0.60	5.87
103	0.092	0.55	5.13
108	0.089	0.51	4.60
112	0.081	0.46	3.80
116	0.075	0.42	3.16
123	0.066	0.40	2.66
129	0.054	0.39	2.11
135	0.044	0.36	1.62
143	0.031	0.34	1.07

[a] Sample: Ultron, 0% RH.

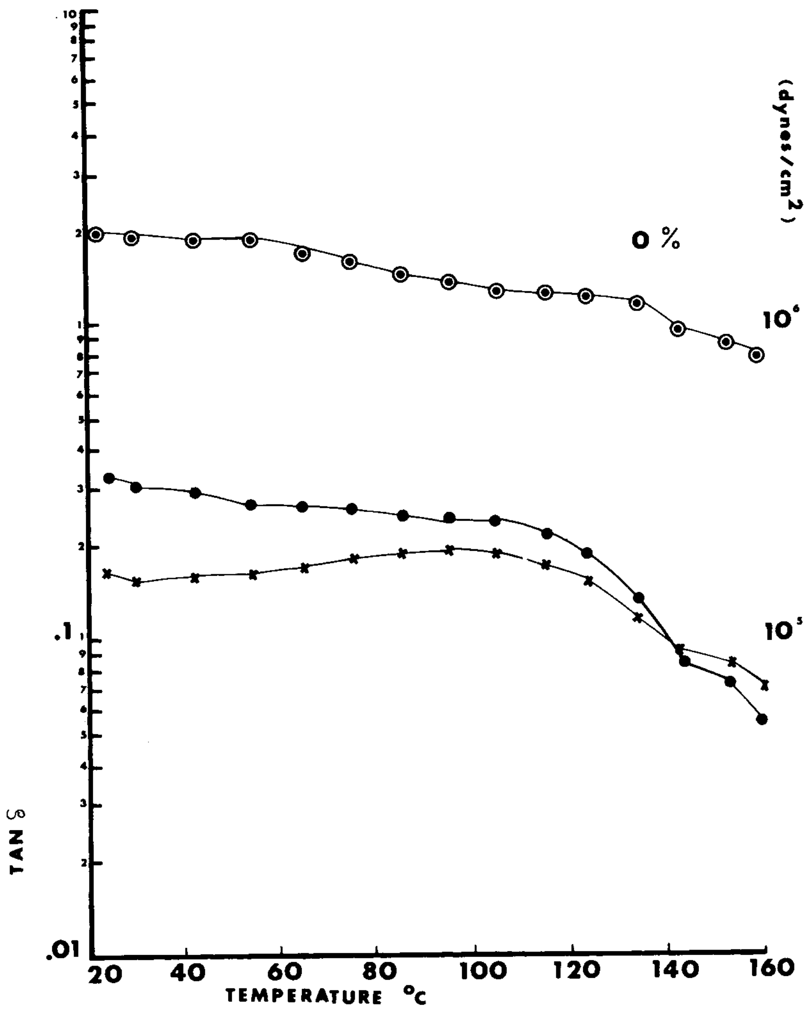

Fig. 2. The dynamic compression data of a fiber mass of the Ultron nylon carpet yarn. ⊙, E'_c; ●, E''_c; × Tan δ. 0% RH.

pated as heat during the deformation. When fiber masses are deformed, part of the energy is stored as potential energy and part is dissipated as heat. The energy dissipated as heat manifests itself as mechanical damping or internal friction. However, the internal friction of fiber masses consists of the internal friction of the constituent fiber and the external friction from fiber to fiber. The external friction can be expressed as follows:

$$\Delta\delta = \tan \delta_{\text{fiber mass}} - \tan \delta_{\text{fiber}}$$

The $\Delta\delta$ values of four fibers are shown in Table I. The highly crimped Acrilan* fiber (B-99) exhibited a high $\Delta\delta$ value, but the cotton fiber shows lower $\Delta\delta$ values because the fibers are straighter. The external friction ($\Delta\delta$) is related to the crimp character and the surface properties of the fibers.

The dynamic compression data of a fiber mass of Ultron as a function of

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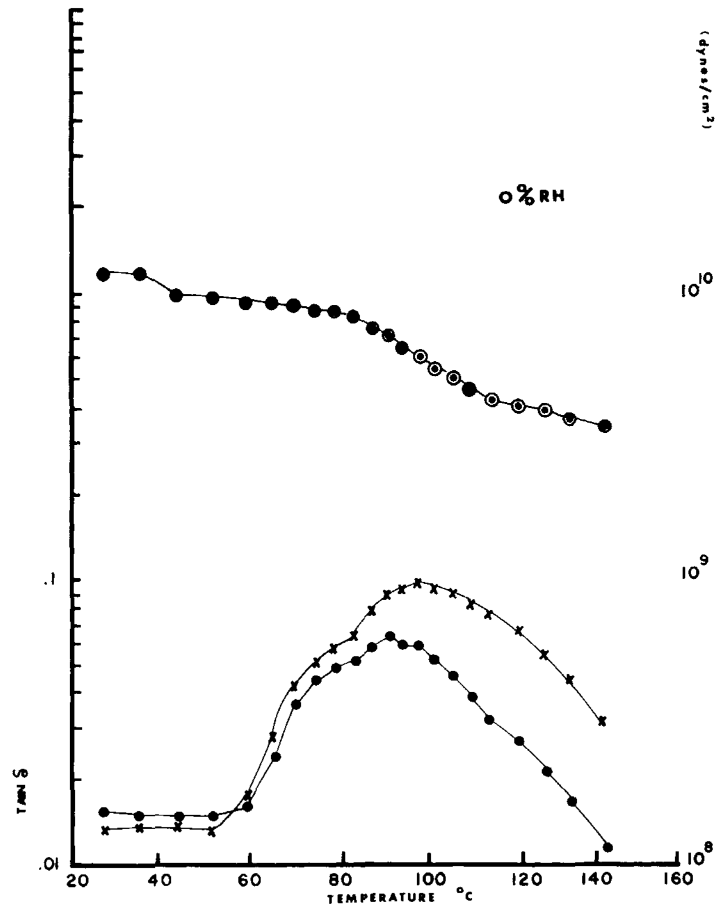

Fig. 3. The dynamic tensile mechanical properties of the Ultron nylon carpet yarn. ⊙, E'_c; ●, E''_c; ×, Tan δ. 0% RH.

temperature are shown in Figure 2 and Table III. The dynamic tensile mechanical properties of the Ultron nylon carpet yarn are shown in Figure 3 and Table IV. The dynamic compression and tensile moduli decrease slowly with increasing temperature in the temperature range of 70–150°C. The loss tangent peak (T_g) of Ultron carpet yarn is about 105°C. The intensity of the α peak (tan δ max) in compression is higher than that from a tensile test. This is a reflection of interfilament friction in the fiber mass during a compression mode test.

This method for measurement of dynamic compression mechanical properties is useful for characterization of properties of fiber masses and similar materials.

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