Dynamic Mechanical Analysis and Image Analysis Characterization of Crimped Yarns

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Synopsis

The Quantimet image analysis system and dynamic mechanical analysis have been applied to characterization of crimped yarns. The image analysis system is useful for obtaining accurate measurements of crimps per inch, uncrimped versus crimped length, crimp wavelength, and crimp amplitude. In addition, the dynamic tensile mechanical properties of fibers and the dynamic compression mechanical properties of the fiber masses were examined. These analyses identify the relationships between crimp parameters and loss tangents for the first time. The loss tangents of fiber masses increase with increasing crimp frequency. The higher loss tangents of crimped yarns in the glassy region quantify both the internal friction of constituent fibers and the external fiber to fiber friction separately.

INTRODUCTION

Investigations of the dynamic modulus and internal friction of fibers over a wide range of temperatures have proved to be very useful in studying the structure and variations of properties of fibers in relation to end use performance. Dynamic parameters have been used to determine the glass transition region, relaxation spectra, degree of crystallinity, and morphologic changes resulting from processing. These variables are based on the internal structure of the polymers. Dynamic mechanical analysis is also useful in determining the properties of structural units such as laminated plastics, fiber-reinforced composites, and textile assemblies. A structural assembly is defined by its joints. These are interfaces or mating surfaces which are maintained in contact. Thus, in analyzing the dynamic properties of a structural assembly, it is important to consider not only the component materials but also the dynamic response and the energy dissipation caused by interface effects.

Textile assemblies (yarns, woven fabrics, knitted fabrics, and nonwoven structures) and fiber-reinforced plastics have extremely large interface areas compared to their volume. The characteristics of the interface have a strong effect on the dynamic mechanical properties of these polymer assemblies. It is the object of this report to describe what has been accomplished with a combination of image analysis and dynamic mechanical measurements for a series of nylon carpet yarns of different degrees of crimp and cross-sectional shape.

EXPERIMENTAL

Dynamic tensile mechanical measurements were made on a Rheovibron viscoelastometer which was operated at a frequency of 11 Hz. Samples were heated at 1°C/min in a nitrogen atmosphere under relaxed conditions, and measure-

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ments of the modulus E and the loss factor tan δ were made at every 5°C, with smaller increments used near the glass transition region. Samples were allowed to equilibrate for 5 min before measurements were made.

In addition to dynamic tensile measurement, the dynamic compression mechanical properties of the fiber masses of nylon carpet yarns were examined by using a new compression technique.[1]

The geometric factors (cross section, shape factor, crimp characteristics) were evaluated by the Quantimet 720-20 Image Analysis System.[2,3] This equipment uses either a light microscope or a macrosystem to project an image onto the face of a high-resolution TV scanner, where the image is converted to a video signal. The signal is then spatially digitized into a matrix of 500,000 individual picture points. The light absorption is determined at each picture point and assigned a six-bit binary word between 0 and 63 defining its individual gray level (from white to black). Gray-level threshold limits are set to detect only those features that are to be measured. Feature selections can be made more specific by applying size or form factor limits. The instrument then counts those picture points that fall within the boundaries of individual selected features. By operator choice, these counts can then be accurately translated into feature parameters such as count, area, perimeter, width, length, etc. The size of individual picture points depends on the optical system and can be calibrated in desired units. The system routines made up of a series of individual instructions can be written using the instrument keyboard and the output "Decwriter" to control which measurements are to be made and also to analyze the data statistically. After the routines are set up and debugged, they are stored on a "floppy disk" and can be changed or erased as needed. Results or routines can be displayed on the monitor or hard copies made on the output printer.

The microscope used with the system is fitted with an x–y stepping stage that can be programmed to step in basic 5-μm increments or multiples of the basic step size. By using the stage, the measuring fields can be abutted to make measurements of every feature in the sample that meets the feature selection criteria.

Measurements such as denier per filament (DPF), apparent modification ratio (AMR), and shape were made on filament cross sections using the microscope and autostage. The feature limits were set to measure only single filaments that do not touch and sections that were cut no greater than 3° off axis. Measurements were as follows:

$$\mathrm{DPF} = A \times d \times 0.009$$

where A is the area and d is the density (1.14),

$$\mathrm{AMR} = P^2/(A \times 4\pi) \times 4/\pi$$

where p is the perimeter, and

$$\mathrm{shape} = A/P^2$$

and A/P^2 for a long needle is about 0.005 and for a perfect circle, 0.07958.

Measurements of fiber crimp factors, crimps per inch, crimp spacing, crimp wavelength, crimp amplitude, and uncrimped versus crimped length were made on the macrosystem, using intact fibers taped to a glass plate. The software (BASIC) for the crimp analysis has recently been developed for use with the image

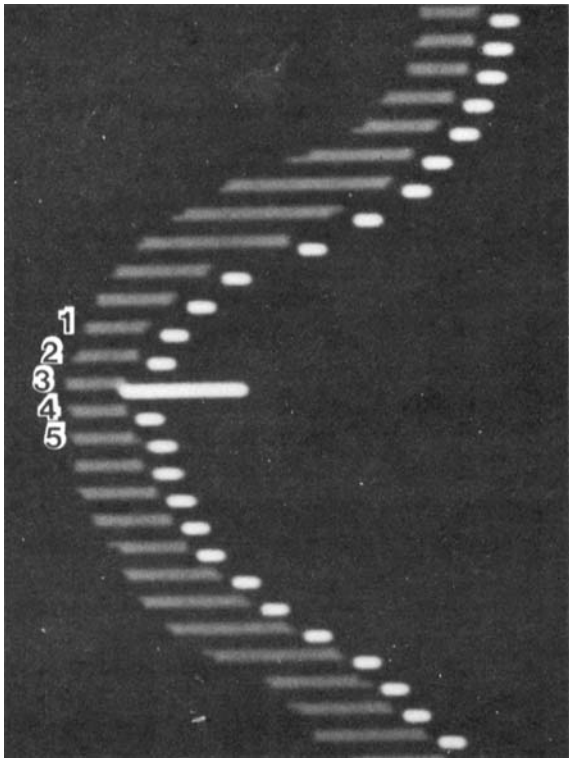

Fig. 1. Measurement of crimp by Quantiment Image Analyzer photograph from instrument CRT screen.

analyzer by our laboratory and the Cambridge Instrument Co. A small module called a "frame smasher" has been added to the image analyzer that connects picture points together to make lines of detection. The analyzer is calibrated in inches, and the sample fibers are measured vertically with the x and y coordinates of the trailing edge of the sample fiber stored on disc memory. After the entire fiber has been measured, the measurements are compared in groups of five. The average of the coordinates of the two preceding measurements and the two measurements after each individual measurement are compared. If the individual measurement is greater or less than the comparison measurements,

TABLE I
Dynamic Mechanical Properties of Nylon Carpet Yarns

	Dynamic tensile		Dynamic compression		
Sample No.	T_g, °C	tan δ_{max}	T_g, °C	tan δ_{max}	tan δ_C 25°C
1	110	0.083	115	0.205	0.190
2	100	0.097	100	0.190	0.165
3	102	0.097	109	0.155	0.137
4	107	0.096	107	0.150	0.135
5	104	0.095	115	0.195	0.165
6	105	0.093	103	0.165	0.102
7	105	0.092	104	0.130	0.147
8	91	0.135	96	0.170	0.185

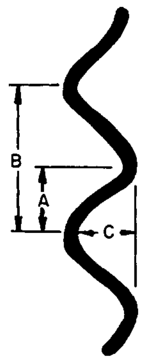

Fig. 2. Crimp form: (A) crimp spacing; (B) crimp wavelength; (C) crimp amplitude.

then it is a deflection point and will be visually marked with a "flag" on the CRT image of the sample.

In Figure 1, the average measurements of detection lines 1 and 2 and 4 and 5 are compared to line 3. Line 3 has a lower value and shows the deflection flag. Using the stored coordinate values, the following calculations are made:

crimp spacing = distance (in.) from minimum to maximum deflection (valley to mountain)

crimp wavelength = distance (in.) from maximum to maximum deflection (mountain to mountain)

crimp amplitude = height of wave (in.)

crimps per in. = (number of deflection points in measuring frame/2)/L

where L = extended length of fiber (perimeter/2).

$$\text{uncrimped vs. crimped length (\%)} = 100 - [(L_0/L) \times 100]$$

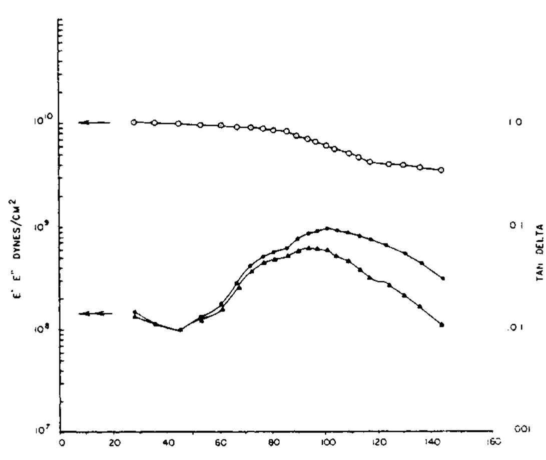

Fig. 3. Dynamic tensile mechanical properties of nylon 66 yarn. (⊙) E′; (▲) E″; (●) tan delta.

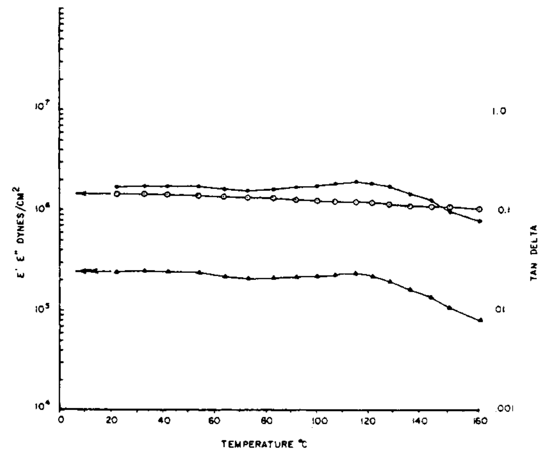

Fig. 4. Dynamic compression mechanical properties of nylon 66 fiber mass. Symbols as in Fig. 3.

where L_0 = length of measuring frame and L = extended length of fiber (perimeter/2). Figure 2 shows crimp form.

Up to 50 individual filaments can be run and the output gives the average wavelength, amplitude, uncrimped versus crimped length, and crimps per inch, and a histogram with crimp amplitude on the x axis and the crimp spacing on the y axis.

RESULTS AND DISCUSSION

The eight crimped nylon 66 yarns are examined by image analysis and dynamic mechanical analysis. The representative dynamic tensile mechanical properties (dynamic modulus E', loss modulus E'', and loss tangent tan δ) are shown in Figure 3. The dynamic tensile moduli show large changes in a temperature range of 90–140°C. The T_g, denoted by the maximum in tan δ, of these crimped nylon yarns is about 105°C. The T_g values and the values of tan δ_{max} are summarized in Table I. The intensity of the α peak (tan δ_{max}) on sample 8 is higher than that of sample 2 fiber. This reflects the amount of amorphous volume in the fiber structure.

The representative of the dynamic compression mechanical properties of fiber masses are summarized in Figure 4 and in Table I. For this compression test, a new compression grip and procedure were used with a Rheovibron viscoelastometer. This method is described in a previous article.[1,4] The glass transition (α peak) is observed by these fiber mass tests. The T_g values by tension and compression measurements are in good agreement. The intensity of the loss tangent (tan δ value) in a temperature range of 25–110°C is significantly different. The higher loss tangent in the glassy region corresponds to the inherent internal friction of the fibers and fiber-to-fiber friction caused by crimp. A summary of the crimp analysis on these carpet yarns is shown in Table II.

Table III shows the results of denier per filament (DPF), apparent modification ratio (AMR), and shape measurements. The values of crimp per inch, crimp wavelength, and crimp amplitude are plotted in Figure 5. These parameters show an approximately linear relationship. The fibers having higher crimps per inch indicate lower crimp amplitude and wavelength. The relationship

TABLE II
Summary of Crimp Analysis on Nylon Carpet Yarns

Sample No.	Crimps per inch		Crimp amplitude, in.		Crimp wavelength, in.		Uncrimped vs. crimped length, %	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
1	9.155	1.975	0.015	0.013	0.088	0.060	13.080	4.46
2	8.726	1.795	0.019	0.011	0.94	0.046	13.071	2.81
3	7.675	1.062	0.022	0.013	0.106	0.050	13.840	3.15
4	7.414	1.863	0.018	0.012	0.116	0.060	10.536	2.37
5	8.637	1.604	0.019	0.012	0.094	0.044	14.018	4.13
6	5.601	1.416	0.030	0.017	0.146	0.086	14.845	4.95
7	7.823	1.097	0.018	0.009	0.108	0.040	11.080	2.28
8	9.192	2.272	0.017	0.011	0.086	0.042	13.689	6.69

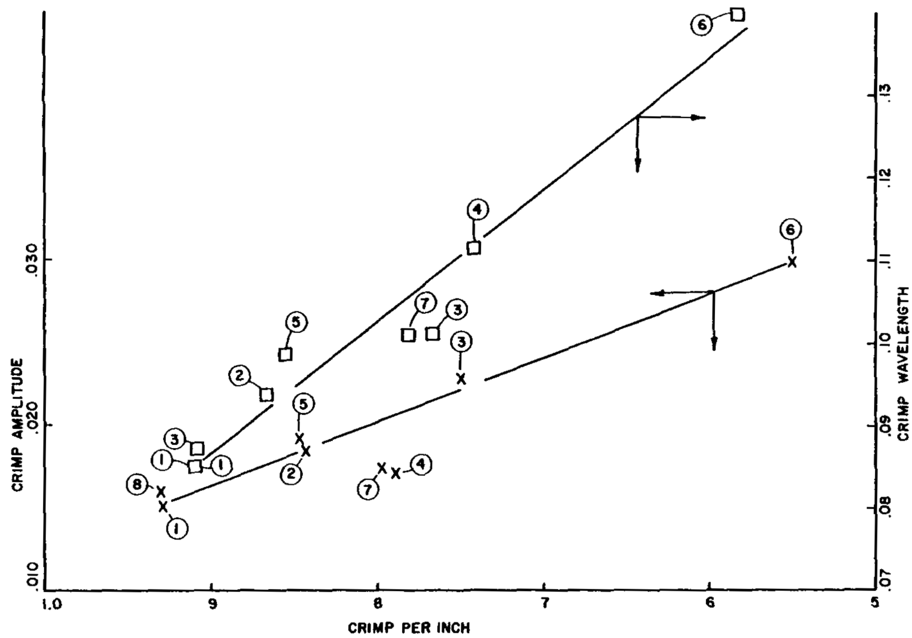

Fig. 5. Relationships among crimp wavelength, crimp amplitude, and crimp per inch.

between crimp parameters (crimps per inch, crimp amplitude) and loss tangents at 25°C by the compression test is shown in Figure 6. The loss tangents of fiber mass increase with increasing crimps per inch, indicating that the highly crimped fiber has a high fiber-to-fiber friction.

As a result, the following conclusions are drawn:

(1) The Quantimet image analysis system is useful for obtaining accurate information on microcrimp formation.

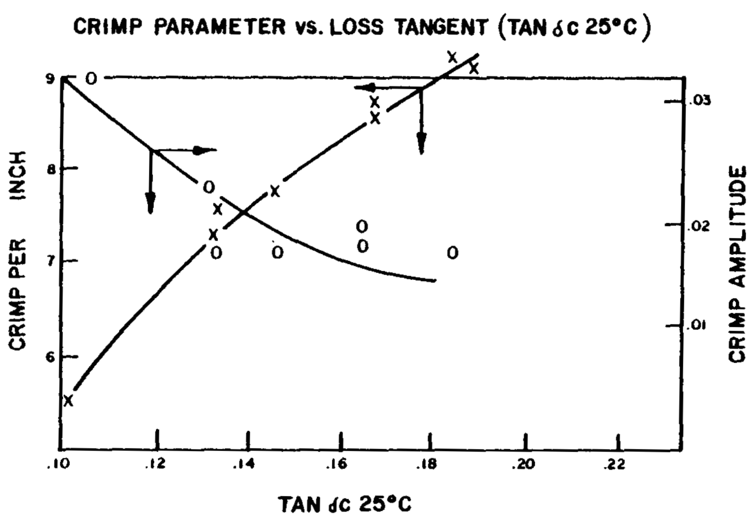

Fig. 6. Relationships between crimp parameters and loss tangent.

TABLE III

Summary of Denier per Filament (DPF), Apparent Modification Ratio (AMR), and Shape on Nylon Carpet Yarns

	DPF				AMR				Shape			
Sample No.	Mean	Min.	Max.	Std. dev.	Mean	Min.	Max.	Std. dev.	Mean	Min.	Max.	Std. dev.
1	10.27	7.2	14.0	1.14	1.64	1.45	2.10	0.114	0.062	0.048	0.070	0.004
2	15.19	9.1	21.2	1.83	1.64	1.46	1.90	0.083	0.062	0.053	0.070	0.003
3	13.72	8.1	20.8	2.37	1.68	1.46	1.91	0.085	0.060	0.053	0.070	0.003
4	16.32	9.1	21.1	1.93	1.71	1.47	1.94	0.101	0.060	0.053	0.067	0.003
5	10.19	8.0	20.1	2.06	1.78	1.57	1.94	0.081	0.057	0.052	0.064	0.003
6	17.80	15.0	23.9	1.86	1.83	1.47	2.38	0.176	0.0558	0.0425	0.0687	0.0053
7	19.86	15.0	24.0	1.72	1.83	1.55	2.57	0.135	0.0557	0.0394	0.0655	0.0040
8	18.93	5.1	63.2	5.58	2.74	2.20	3.45	0.259	0.0373	0.0294	0.0461	0.0035

(2) The higher loss tangents of crimped yarns in the glassy region quantify both the internal friction of constituent fibers and the external fiber-to-fiber friction separately.

(3) The relationship between crimp parameters and loss tangents is established for the first time by using these analyses.

References

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