The Use of Crossflow to Improve Nonwoven Melt-Blown Fibers

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SYNOPSIS

A stream of unheated crossflow air has been used to make finer melt-blown fibers. Not only are smaller average fiber diameters obtained, but the variation in fiber diameter is smaller. The use of this technique can allow the production of melt-blown nonwovens, which have finer fibers and more uniform webs. Since unheated air is used in the crossflow jet, the fiber enhancement in terms of finer, stronger fibers can be achieved with an energy savings by substituting unheated crossflow air for a portion of the primary air.

INTRODUCTION

Melt blowing technology has gathered momentum in recent years in terms of growth of production and the development of a variety of new products due to the unique ability of the process to produce webs consisting of ultrafine microdenier fibers. The webs exhibit superior properties for filtration, insulation, barrier, and absorption media due to the microfibers. A large amount of work has been done in the past few years by many authors on resin characteristics, process conditions, web structure, and properties relationship,[1-5] the characterization of melt-blown fibers and webs,[6-9] and attempts to model mathematically the process.[10-12] There is still a need to better understand the mechanism of the fiber formation in the process, so as to develop ways to make finer fibers and more uniform webs, which are paramount to the improvement of the final products.

A great deal of effort has been devoted at the University of Tennessee to the development of a fundamental understanding and improvement of the melt blowing process. This effort led to an important finding by Milligan[13] in 1987 when he discovered that the fiber form drag, due to large amplitude flapping of the melt thread being blown away from the die, plays a significant role in the total air drag force and hence becomes a major factor for fine fiber formation in the process. Based on that finding, the present article presents a method for producing finer and more uniform fibers by using a crossflow to the primary air jet to increase the flapping of the melt thread in both amplitude and frequency. This investigation was conducted on a single orifice melt blowing die. The effect of crossflow on web properties, as exhibited in multihole dies, is currently under investigation and will be reported later. The mechanism of the fiber formation has been developed in detail in other publications.[14]

EXPERIMENTAL ARRANGEMENT AND TECHNIQUES

The polymer used in this study was commercial Exxon homopolypropylene resin of 800 MFR in the form of granule (Exxon Grade 3495G). The configuration of the single orifice die with crossflow chamber is shown schematically in Figure 1. The single orifice had a diameter of 0.356 mm and an L/D of 8.5. The air knife gaps and the setback of the die nosepiece were 2 mm. The distance from the die face to the crossflow slit is the dimension "b" and the distance from the crossflow slit to the primary jet centerline is dimension "a." The crossflow slit was 0.0813 cm wide and was machined in a 1.27 cm pipe. The pipe manifold was connected to a high pressure air line through a pressure regulator. The dimension "h" is the width of the slit and α is the angle between the slit and a vertical line. The α is

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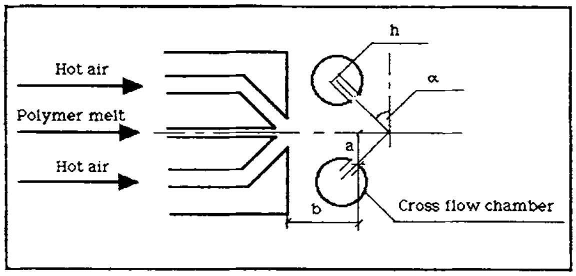

Figure 1 Schematic of arrangement of single orifice die with crossflow chamber in place.

defined as being positive as the slit is tilted away from die face and vice versa. The single orifice die was connected to an extruder, which has a screw diameter of 2.54 cm and an L/D of 24. The primary air temperature and pressure were measured in a stagnation chamber inside the die. The melt throughput was determined by collecting the fiber over a measured time period and by weighing the extruded web. The process conditions used are similar to commercial processing conditions.

Photographs of the melt thread in the fiber forming process were taken by means of a high speed photographic technique. The "frozen" image of a single continuous fiber was obtained at a flash exposure of one five-hundred thousandth of a second.

SAMPLE PREPARATION AND EVALUATION

Fiber samples were collected at a die-to-collector distance (DCD) of 30 cm in such a way that a single layer of fiber was "sprayed" on a black paper sheet and could easily be transferred to a slide for diameter and birefringence microscopic measurement. Fiber diameter and birefringence were determined on a Zeiss polarizing microscope, equipped with a reticulated ocular marked for 1 cm in 100 increments. An overall magnification of 400 was used and every fiber within the view area of the microscope was measured. For each sample, 40 to 50 diameter measurements from several different focus areas, selected at random, were averaged to give a simple number average diameter value. The optical retardation of the fiber was determined using a 5λ Berek compensator. Fiber birefringence is the ratio of its retardation to diameter.

RESULTS

Figure 2 shows the experimental data for two different melt temperatures with no crossflow. As noted in these data, the average diameter appears to be-

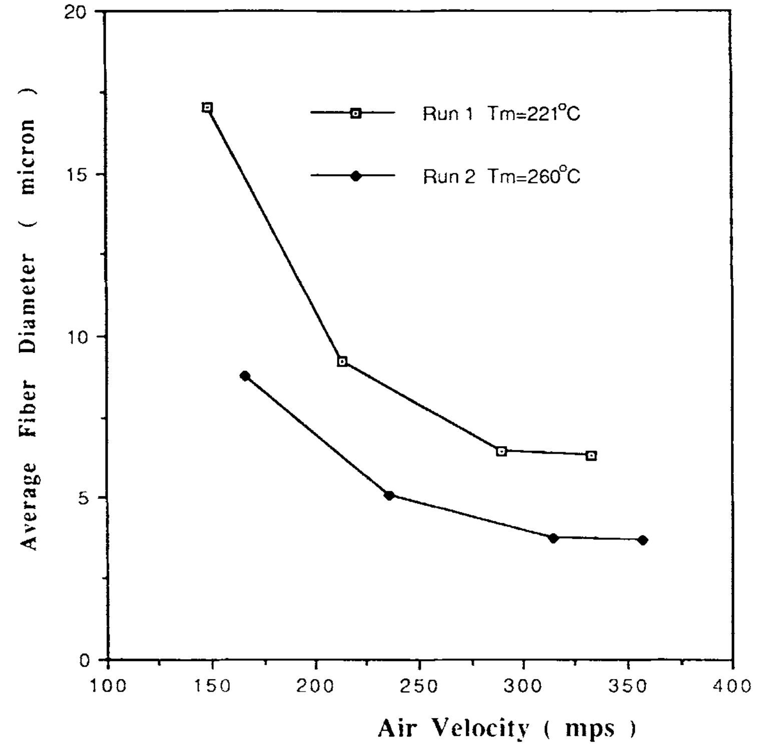

Figure 2 The effect of air velocity on fiber diameter with no crossflow.

come relatively insensitive to air velocity at the higher velocities. These data are contrary to what many investigators have indicated. Most prior investigators indicate that the diameter of the fibers produced is determined by the "draw ratio." They have defined the "draw ratio" as the ratio of air velocity to extrudate velocity. Their theory would result in a diameter dependence contrary to that shown in Figure 2.

Table I indicates typical variables used in the present investigation. Significant reduction in average fiber diameter is apparent for most of these tests. The last column in Table I is simply the fraction reduction in fiber diameter based upon the no-cross-flow reference. Figure 3 shows data obtained for different angles, α, with the crossflow jet on only one side of the fiber thread. It is obvious that an optimum angle exists for the fixed values of processing conditions, slit location, and crossflow pressure or velocity. Figure 4 shows data for average fiber diameter as a function of crossflow velocity. Again it is obvious that an optimum crossflow velocity exists for this set of conditions. Figure 5 shows data similar to Figure 4, but for a melt temperature of 260°C rather than 221°C. A different optimum crossflow velocity is indicated by these results.

In Figure 6, the average fiber diameter is shown as a function of throughput for the conditions of no crossflow and with crossflow. There was a significant reduction in diameter due to crossflow for all values of throughput. The diameter reduction due to crossflow varied from about 40% at the lower throughput to 20% at the higher throughput. Figures 7 and 8 are histograms, illustrating the effect of crossflow on the distribution of fiber diameters. The processing conditions are the same for both sets of data, except the data in Figure 8 were obtained with crossflow. It can be noted that the average fiber diameter decreased from 5.07 μ to 2.83 μ and the standard deviation decreased from 2.56 μ to 1.11 μ as a result of the crossflow. The diameter distribution with crossflow is much narrower, which means that a finer and more uniform web can be produced with the crossflow technique.

It is well-known that fiber birefringence can be used as an index to evaluate mechanical properties of the fiber, as well as the resulting web. The higher the birefringence, the higher the fiber strength and thus the web strength. Figures 9, 10, and 11 show the relationship between birefringence and fiber diameter for fibers under different melt blowing conditions. Figure 9 shows the data for the effect of crossflow, Figure 10 the effect of throughput, and Figure 11 the effect of melt temperature. It can be noted that fiber birefringence is basically a function of the fiber diameter without any first order depen-

Table I Typical Crossflow Processing Variables

Experiment Condition						Results	
Tm (°C)	Primary Air Velocity (m/s)	Crossflow Velocity (m/s)	a (cm)	b (cm)	α	$\overline{Dn}$ (μ)	$\frac{\overline{Dn}_1 - \overline{Dn}_2}{\overline{Dn}_1}$
221	332	0	—	—	—	6.3	—
221	332	200	1.27	1.27	−45°	4.7	0.25
221	332	200	0.95	1.9	0°	4.8	0.24
221	332	411	1.27	3.2	45°	5.5	0.13
221	213	0	—	—	—	10.6	—
221	213	200	0.95	2.9	10°	9.93	0.06
221	213	200	1.27	3.8	45°	10.89	−0.03
221	213	200	3.2	2.54	0° (one side)	6.04	0.43
221	213	0	—	—	—	10.85	—
221	213	200	0.95	1.6	−20° (one side)	6.17	0.43
260	221	0	—	—	—	5.07	—
260	221	200	0.95	0.95	−20° (one side)	2.83	0.44

$\frac{\overline{Dn}_1 - \overline{Dn}_2}{\overline{Dn}_1}$ is the fiber diameter reduction ratio resulting from crossflow effect.

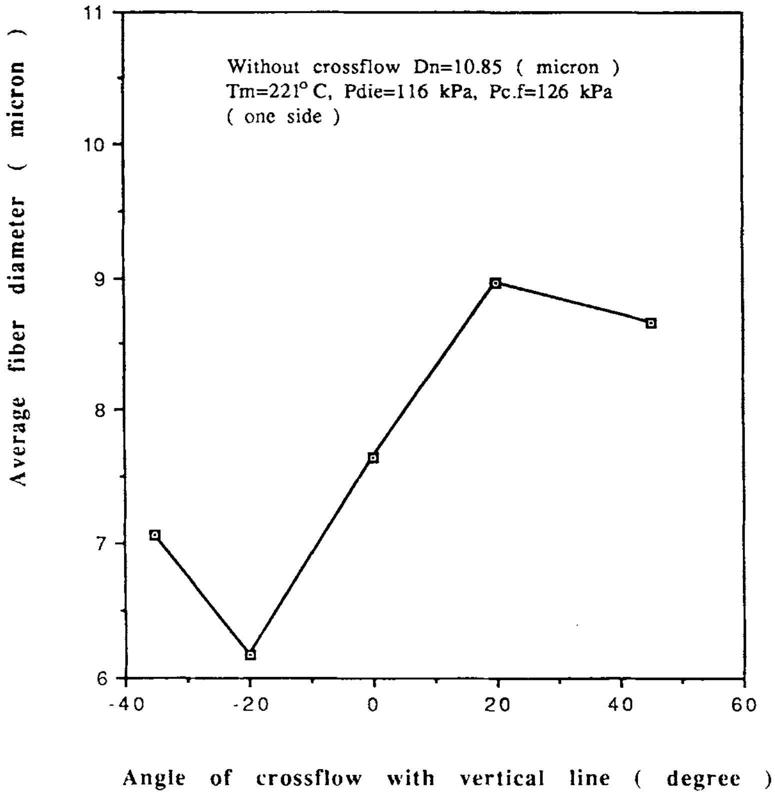

Figure 3 The effect of crossflow injection angle on fiber diameter.

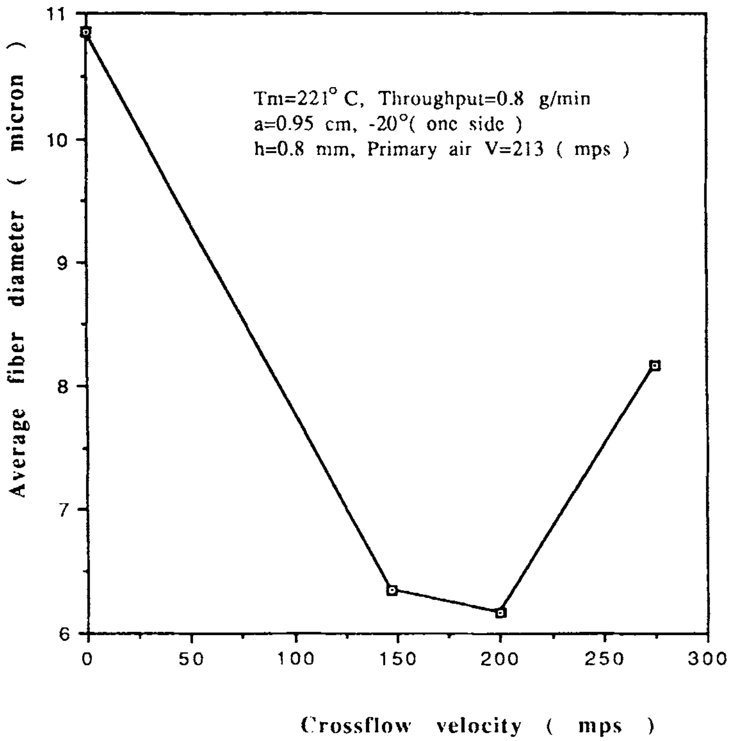

Figure 4 The effect of crossflow velocity on fiber diameter for 221°C melt temperature.

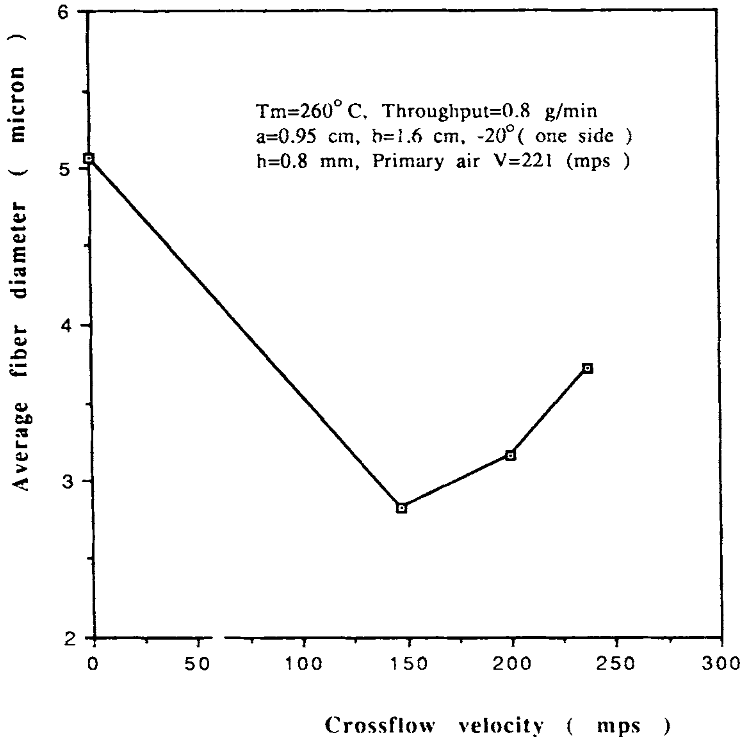

Figure 5 The effect of crossflow velocity on fiber diameter for 260°C melt temperature.

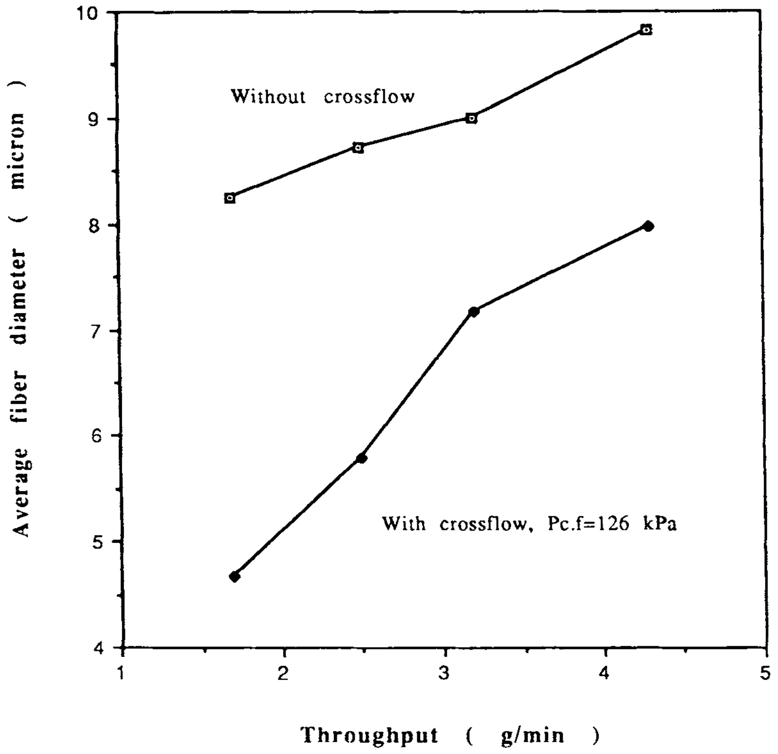

Figure 6 The effect of throughput on fiber diameter with and without crossflow.

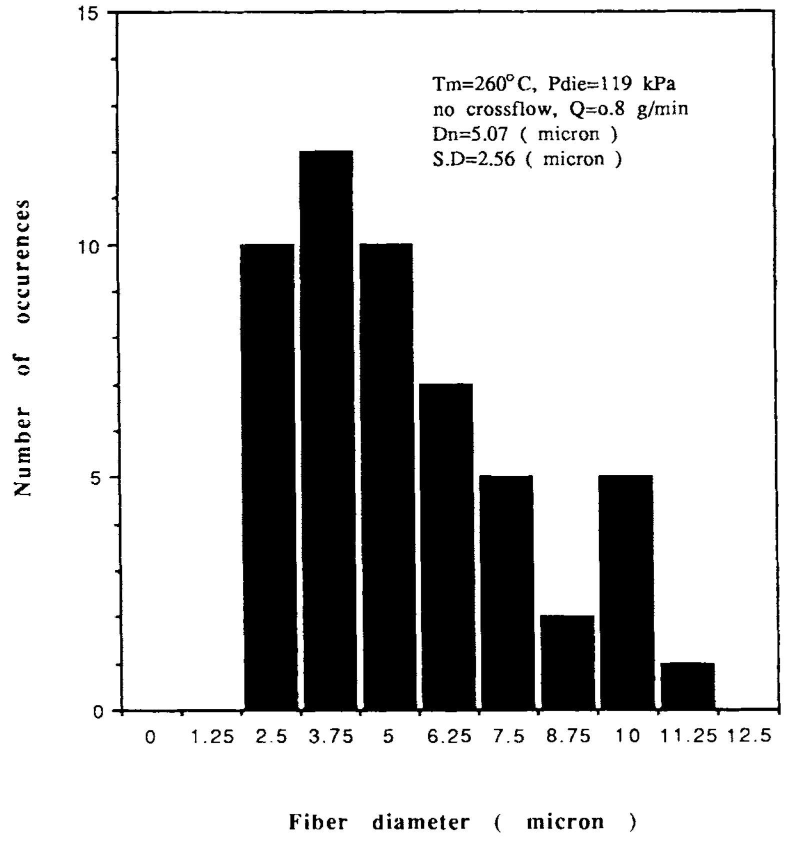

Figure 7 Histogram for fiber diameter with no crossflow.

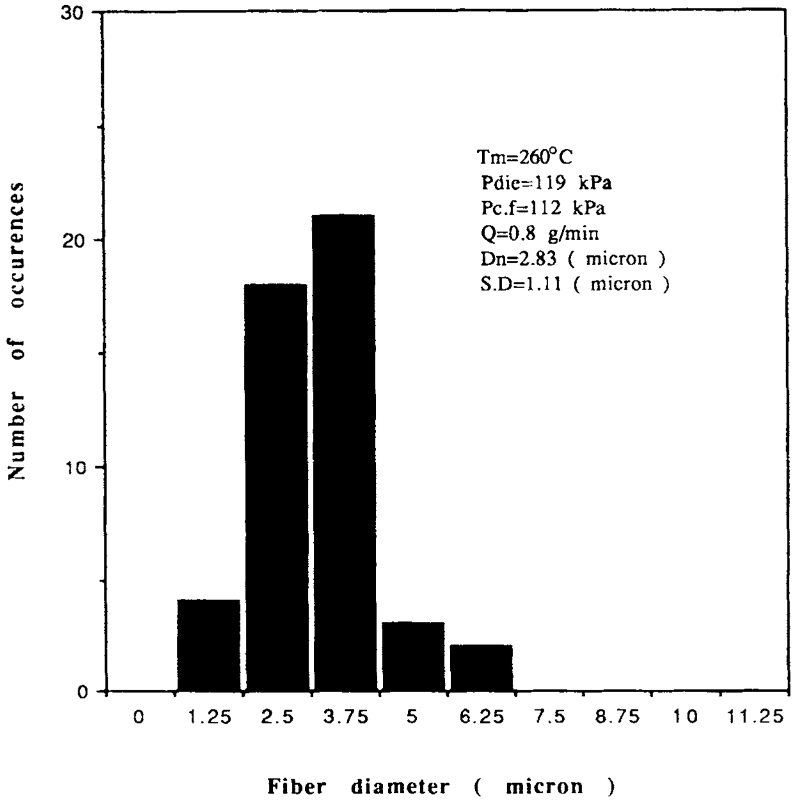

Figure 8 Histogram for fiber diameter with crossflow.

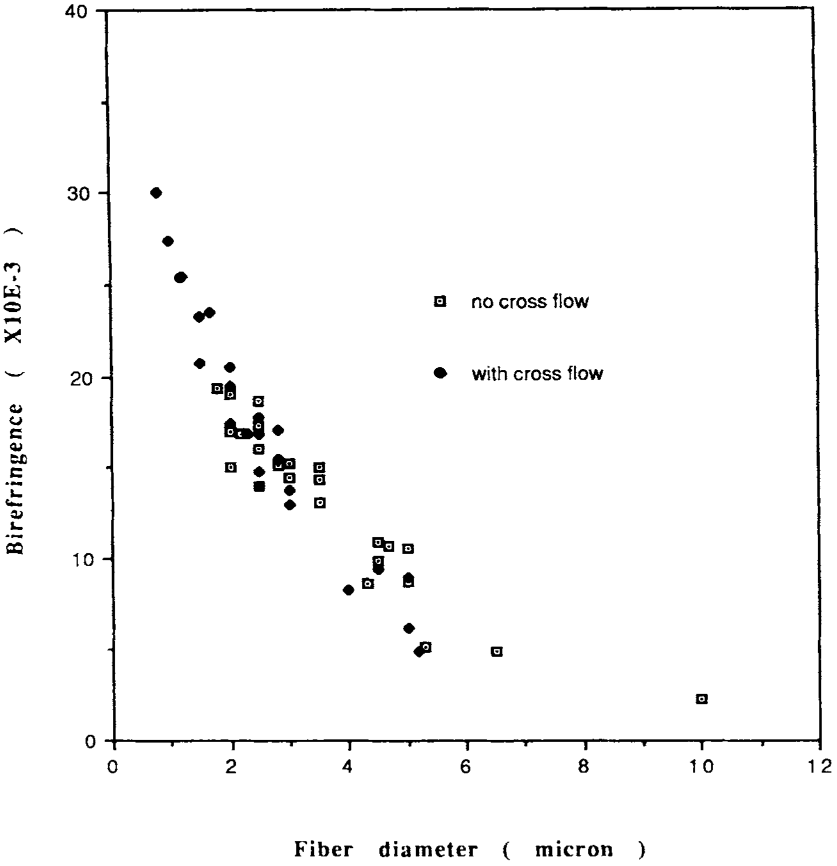

Figure 9 Birefringence vs. fiber diameter with and without crossflow.

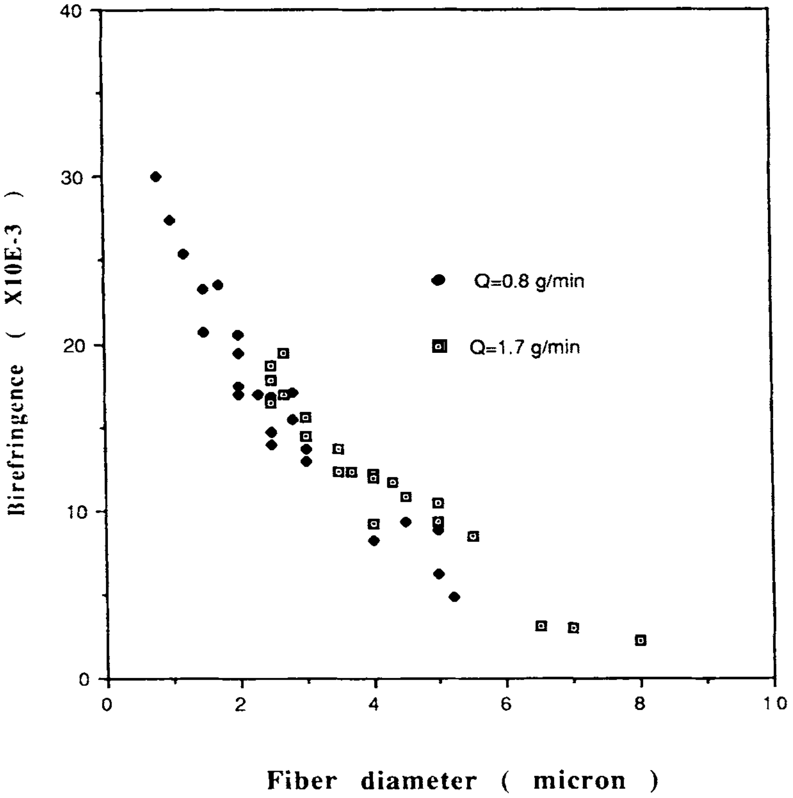

Figure 10 Birefringence vs. fiber diameter for different throughput.

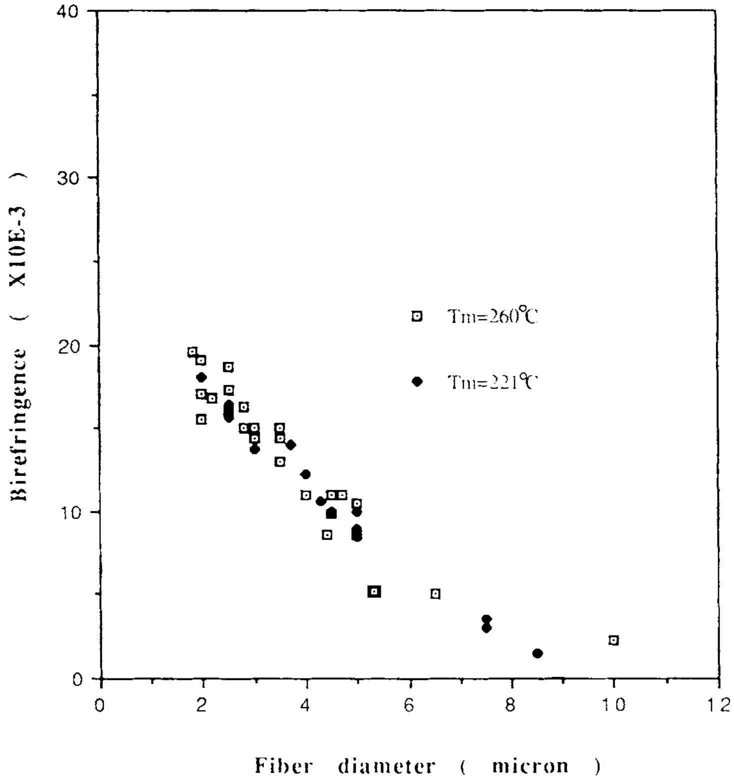

Figure 11 Birefringence vs. fiber diameter for different melt temperatures.

dence on the processing condition that produced the fiber. The implication of this is that molecules in the fiber may undergo a similar path of alignment, from random in the melt to partially oriented in the fiber, during the melt blowing process. Thus we might expect that the finer fiber, which has experienced greater drawing or attenuation, will have higher total molecular orientation and hence higher birefringence. Since fibers produced with the crossflow technique have smaller diameters, it is expected that the strength performance of melt blown webs produced with crossflow will be enhanced.

Figures 12 and 13 are high speed photographs showing the fiber shape with and without crossflow. The only processing difference between the two photographs is crossflow. It is apparent that the crossflow has resulted in a different thread shape. Not only is the non-streamlined shape developed closer to the die tip, but the amplitude of the deviations are larger. Obviously, the aerodynamic form drag on the crossflow shape was greater than on the noncrossflow shape. This fact is exhibited in that finer fibers are obtained with crossflow. Also the accelerated fiber cooling, due to the cold crossflow air, results in increased fiber toughness.

CONCLUSIONS

Based upon this investigation, the dominant conclusion is that the use of crossflow can result in finer, more uniform fiber formation. This should permit production of not only finer, more uniform webs, but also stronger webs. In addition, crossflow can be used to produce comparable webs with less energy cost since the use of unheated crossflow air will allow a reduction in the amount of heated primary air that is required.

Several other conclusions can be drawn from this investigation.

1. The aerodynamic form drag is the dominant force in fiber attenuation.
2. Crossflow is an effective technique to increase form drag by changing the thread or fiber shape.
3. Any crossflow configuration, which increased fiber flapping, resulted in smaller average fiber diameters and vice versa.
4. The optimum crossflow design will depend on processing conditions, such as melt temperature, throughput, and the polymer being blown with the overriding aspect being the

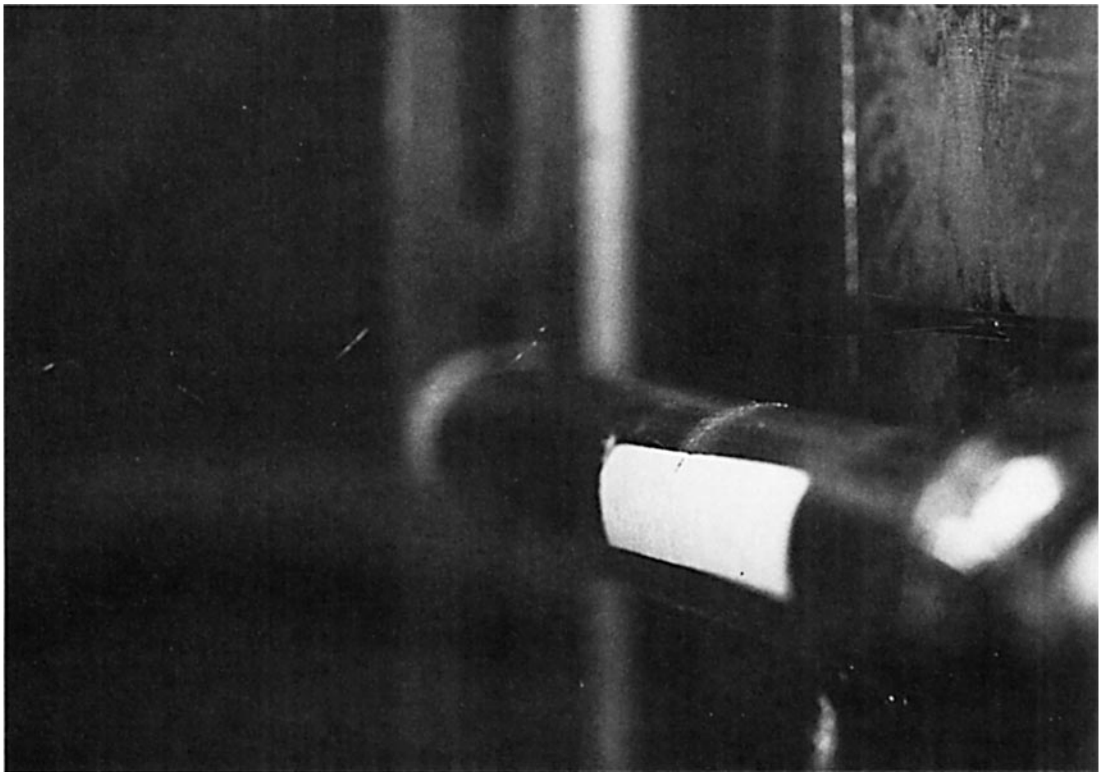

Figure 12 Photograph of melt blowing with no crossflow.

Figure 13 Photograph of melt blowing with crossflow.

design, which enhances fiber "flapping or whipping" and results in the maximum fiber drag.

5. The use of crossflow can result in not only finer (smaller average diameter) fibers, but also more uniform and stronger fibers.
6. Improved fiber toughness and softness can be obtained by using crossflow air.
7. There is a significant potential for energy savings due to the use of unheated crossflow air.

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