

Preliminary Study on Fiber Splitting of Bicomponent Meltblown Fibers

Christine (Qin) Sun, Dong Zhang, Yanbo Liu, Regina Xiao

Textiles and Nonwovens Development Center (TANDEC), The University of Tennessee, Knoxville, Tennessee 37996

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ABSTRACT: Side-by-side bicomponent meltblown fiber webs were developed on REICOFIL[®] bicomponent (bico) meltblown line at The University of Tennessee's Textiles and Nonwovens Development Center (TANDEC), using polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polyamide (PA), polytrimethylene terephthalate (PTT), and so forth. The posttreatment was performed by hydroentanglement to investigate the fiber-splitting behavior in this research. Mi-

croscopy analysis and SEM were applied to examine the web structure. The change in web property after posttreatment and the adhesion mechanism of the polymer interface were also addressed. © 2004 Wiley Periodicals, Inc. *J Appl Polym Sci* 93: 2090–2094, 2004

Key words: hydroentanglement; meltblown bico fibers; structure; fiber splitting; adhesion

INTRODUCTION

Various bicomponent (bico) meltblown fiber webs were successfully produced with bico pairs of polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polyamide (PA6), polytrimethylene terephthalate (PTT), and so forth, at bico weight ratios of 25/75, 50/50, and 75/25.^{1,2} The process development and data analysis were conducted by surface response methodology (SRM) to systematically explore the potentials of novel bicomponent meltblown technology.³ Nonround, side-by-side cross-sectional fiber morphology and more twisted fibers were observed by SEM for the bico meltblown webs, including PP/PBT, PE/PBT, PP/PA, PP/PET, and PE/PET. The smallest fiber diameter achieved was generally in the range of 1.0–2.0 μm . A continuing effort has been made to obtain even finer meltblown fiber nonwovens by subsequent posttreatment to split the side-by-side fibers.

Two approaches were applied at The University of Tennessee's Textiles and Nonwovens Development Center (TANDEC) for the posttreatment: mechanical method and chemical method. The mechanical method was intended to split each component apart in a side-by-side bico fiber using hydroentanglement, which used a pressurized stream of water to split the

bicomponent conjugate meltblown fibers. For chemical treatment, a substantial portion of the conjugate fibers was removed by a dissolving process, which retained the nondissolvable part in the fibers.

In this study, the fiber-splitting behavior of new bico meltblown webs by mechanical method was investigated. SEM and microscopic analysis were applied to examine the web structure. The web properties were evaluated for comparison study before and after the posttreatments, which included basis weight, fiber diameter, air permeability, tensile properties, flexural rigidity, and barrier properties. The interfacial adhesion between two polymers is also discussed.

EXPERIMENTAL

Web preparation

PP/nylon-6, PE/nylon-6, and PET/nylon-6 side-by-side bico meltblown webs were produced using a TANDEC 24-in.-wide bico meltblown line (Reifenhäuser GmbH, Troisdorf, Germany). Table I lists the web description and processing conditions.

Hydroentanglement

The bico web samples in Table I were hydroentangled at Fleissner Nonwovens GmbH (Ansbach, Germany). Three levels of water jet pressure were applied: 80, 100, and 120 bar.

Web characterization

The web test included basis weight, fiber diameter, air permeability (ASTM D 737), tensile properties (ASTM

Correspondence to: D. Zhang (dzhang@utk.edu).

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TABLE I
Sample Description and Processing Conditions for the Bicomponent Webs^a

Sample ID	Sample description	Melt temperature (°F)	Melt throughput (g/h/min)	Air temperature (°F)	Air flow rate (scfm)	DCD (in)
1	25PP/75PA6	590/590	0.55	600	350	8.0
2	50PP/50PA6	590/590	0.55	600	350	8.0
3	75PP/25PA6	590/590	0.55	600	350	8.0
4	25PE/75PA6	570/590	0.55	590	550	8.0
5	50PE/50PA6	570/590	0.55	590	550	8.0
6	75PE/25PA6	570/590	0.55	590	550	8.0
7	50PET/50PA6	590/590	0.73	590	520	8.0
8	25PET/75PA6	590/590	0.73	590	520	8.0

^a For Samples 1–6, air gap/setback = 0.8/1.0 mm, using filtered die. For Samples 7 and 8, air gap/setback = 1.5/1.5 mm, using nonfiltered die.

D 1117), flexural rigidity (ASTM D 1338-64), and hydrostatic head (IST 80.4-92). In addition, microscopic analysis and SEM were applied to examine the web structure. Webpro image-analysis software, which randomly selected 256 microscope images for evaluation, was used to measure the web uniformity.^{4,5}

RESULTS AND DISCUSSION

Fiber splitting by hydroentanglement

To examine fiber structural development of the bico meltblown webs after hydroentanglement, SEM observations were extensively conducted on hydroentangled PA/PP, PA/PE, and PA/PET bico meltblown webs. Fiber splitting was detected for these three paired webs, which appeared more promising compared to PP/PE, PP/PET, and PBT/PTT bico meltblown webs in a previous test in which no fiber splitting was achieved by hydroentanglement.⁶ However, a greater amount of fiber breakage than splitting occurred after the hydroentanglement, as the SEM images show in Figure 1. This indicates that the bico meltblown fibers might be too weak to achieve the overall fiber splitting by the mechanical method, even with such incompatible paired bico fibers, such as PA/PP and PA/PET, which were previously proved to be splittable by hydroentanglement for the spunbond bico fibers.⁷

Generally speaking, autogenously bonded meltblown fiber webs are quite weak because of very low molecular orientation. They have numerous interfiber bonds, which are formed when the filaments are still tacky as they are collected. The bonds restrict fiber movements. Therefore, these webs are difficult to split with a mechanical splitting process, such as hydroentanglement, without damaging the fibers. A basic understanding of polymer interfacial adhesion appears necessary to minimize the interfacial bonding strength and promote fiber splitting.

Interfacial adhesion

The polymer pairs selected for this study (PA/PP, PA/PE, PA/PET) are basically incompatible and their diffusion coefficients are quite small, and thus interdiffusion of entire macromolecules across the interface is unlikely. However, local segmental diffusion is theoretically and experimentally known to occur readily, forming a diffuse interfacial layer of 1–5 nm between two incompatible polymers, as shown in Figure 2. Such local segmental diffusion is favored thermodynamically, given that interfacial free energy is minimized by limited interdiffusion, and kinetically possible segmental movement is confined locally. When the composite structure is cooled from a molten state, the individual chains lose mobility and the existing entanglements act as physical bonds that will tie the two polymers together across the interfacial region.

Therefore, interdiffusion is a basic (and the first) process for interfacial adhesion. The diffuseness of the interface significantly affects the mechanical strength of the interface. The intermolecular bonding is ready to form only after the intimate contact between different molecules occurs. The interfacial forces holding the two phases together may arise from various types of intermolecular forces, such as van der Waals forces, chemical bonding, or electrostatic attraction.⁸ The van der Waals force between two molecules is a short-range force, varying with the intermolecular distance. It includes dispersion force, dipole force, induction force, and hydrogen bonding. The chemical bonding at the interface is difficult to detect because of thinness of the interface. Although it is not likely to occur for normal bico pairs, it might occur and contribute to the adhesive strength in some rare conditions.

Variables affecting interfacial adhesion

Interfacial adhesion strength is affected not only by the polymers' properties but also by the equipment

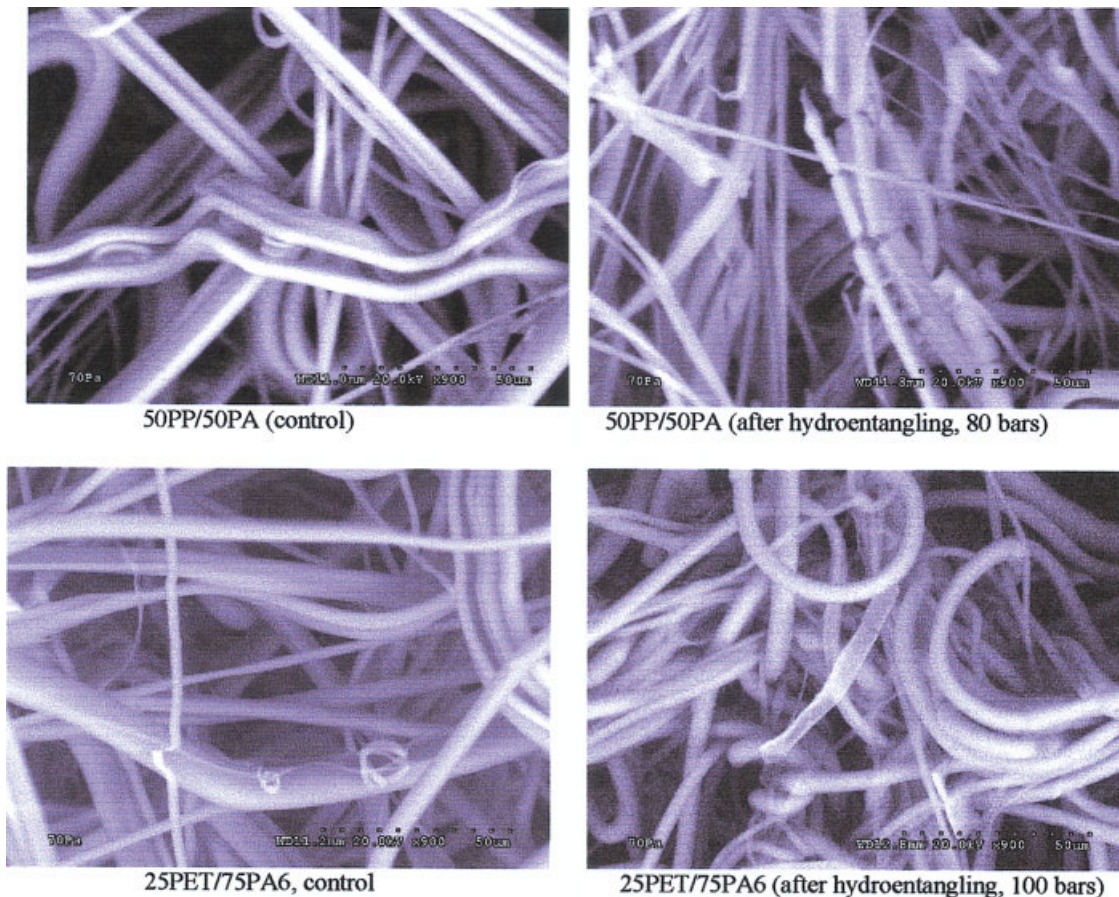


Figure 1 SEM images of the bicomponent (bico) webs before and after hydroentanglement.

parameters and processing conditions, which, in terms of the meltblowing process, include:

1. *Interfacial contact time of two polymer melts during production.* The adhesive bond strength increases significantly with contact time after two melts join together. Therefore, minimizing a two-polymer contact channel in the machine design will favor subsequent fiber splitting.
2. *Melt temperature.* Within a normal temperature range for melt spinning, a higher temperature

will promote molecular segmental diffusion across the interface and enhance the interfacial adhesion.

3. *Pressure.* Adhesive strength normally increases with increasing applied pressure during bonding. For the meltblown process, however, the pressure mainly depends on the melt flow dynamics.
4. *Molecular weight.* Increased molecular weight will increase the viscosity of polymers, which

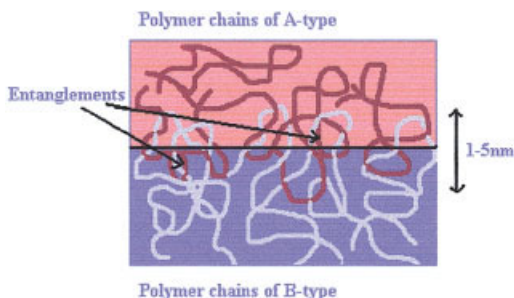


Figure 2 Interdiffusion of macromolecules across the interface of two polymers [from Paul and Newman (1978)⁶].

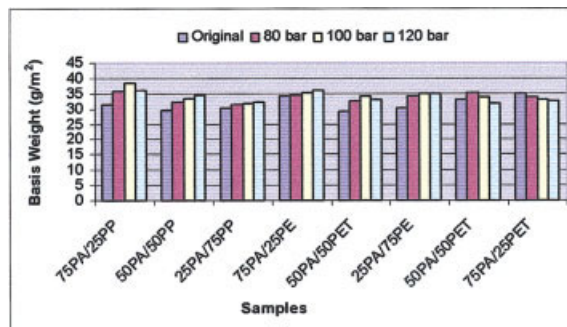


Figure 3 Basis weight of bico webs before and after hydroentanglement.

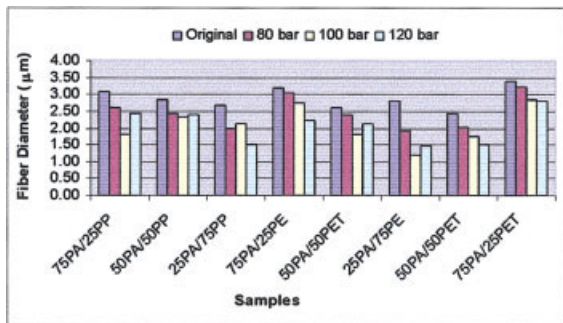


Figure 4 Fiber diameter of bico webs before and after hydroentanglement.

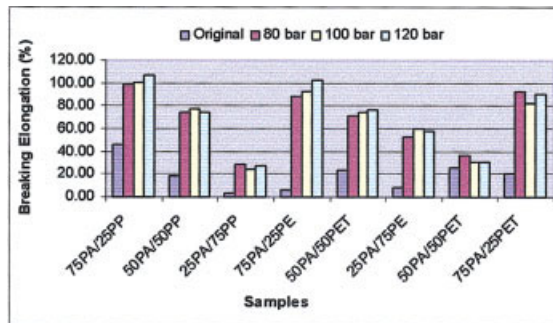


Figure 6 Breaking elongation of bico webs before and after hydroentanglement.

will retard both wetting and diffusion. Thus, the effect of molecular weight on bond strength will be variable, depending on material properties.

5. *Molecular structure or chain flexibility.* Increasing chain rigidity tends to, but not always, decrease the bond strength. Chain rigidity will increase the viscosity and retard the diffusion. Thus, the effect of chain rigidity on adhesion can be variable. However, the bond strength usually tends to decrease with increasing chain rigidity.⁹
6. *Molecular side group, polarity, double bond, and compatibility.*¹⁰
7. *Solidification processes.* Different temperatures, different thermal times or locations, and different mechanisms will affect the structure and properties of the interface. For example, if polymer A crystallizes while polymer B is still a viscoelastic fluid, penetrating segments of A chains might be drawn back from the “interface” in the B side.

Web property change by hydroentanglement

The effect of hydroentanglement varied with the processing conditions, bico composition, and original web structure. Figures 3–6 show the web property before and after the hydroentanglement. The basis weight

was increased because the webs shrunk after treatment (Fig. 3). However, an exception occurred for two PET/PA6 webs, indicating some fiber was lost during the hydroentangling process because the original web structure was very loose. It should be noted that for the bico webs with no shrinkage, such as PP/PE, the basis weight was basically unchanged after the treatment.

Fiber diameter showed a consistent decrease after hydroentanglement (Fig. 4) with fiber splitting. The effect on web strength varied with the original web structure (Fig. 5), which increased significantly for PA/PET webs (50PA/50PET, 75PA/25PET) because the webs were weak with loose fibers before the treatment. However, for well-bonded bico meltblown webs, such as 50PA/50PP, 25PA/75PP, and 75PA/25PE, the web strength decreased after hydroentanglement. Interestingly, for all the web samples, the extension was significantly increased after hydroentanglement (Fig. 6). The webs exhibited excellent softness after the treatment (Fig. 7). Figure 8 shows that air permeability increased with water jet pressure applied for the hydroentangling process. The water resistance (Fig. 9) showed an exact opposite trend to that of the air permeability, which decreased with increase of the water pressure. Therefore, the barrier property was not enhanced by hydroentanglement, even with par-

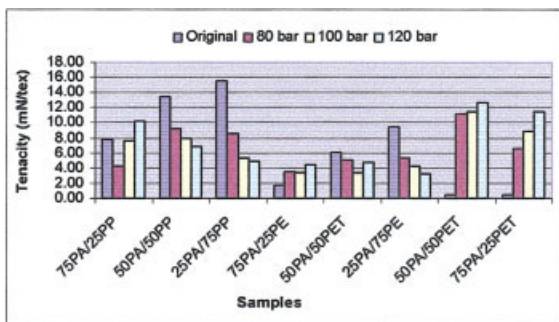


Figure 5 Tenacity of bico webs before and after hydroentanglement.

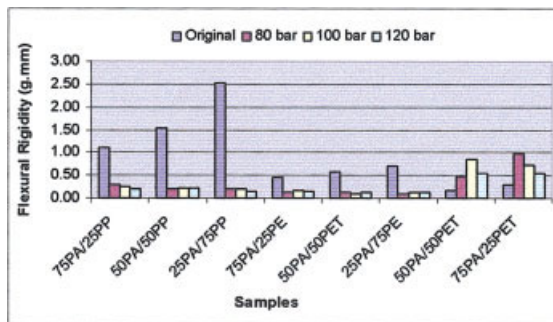


Figure 7 Flexural rigidity of bico webs before and after hydroentanglement.

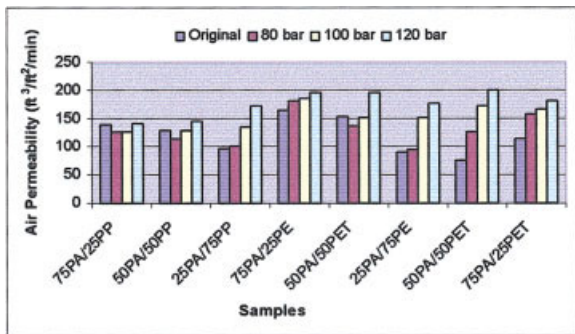


Figure 8 Air permeability of bico webs before and after hydroentanglement.

tial fiber splitting in this case. The main reason might be attributable to deterioration of the web uniformity in a small scale by the water jets during hydroentangling, as shown in Figure 10, measured by Webpro image analysis.

CONCLUSIONS

Fiber splitting was achieved partially by posthydroentanglement for side-by-side bico PP/PA6, PE/PA6, and PET/PA6 meltblown webs, although more fiber breakage than fiber splitting was detected, which indicates that the meltblown fibers were too weak to achieve the overall fiber splitting by mechanical means, that is, if no additive or machine modification is considered to weaken the interfacial adhesion.

The interfacial adhesion between two incompatible polymers in side-by-side bicomponent fibers is formed mainly because of the local segmental diffusion of two polymer molecular chains, given that the interfacial free energy could be minimized by the interdiffusion. The strength of the interfacial adhesion is affected not

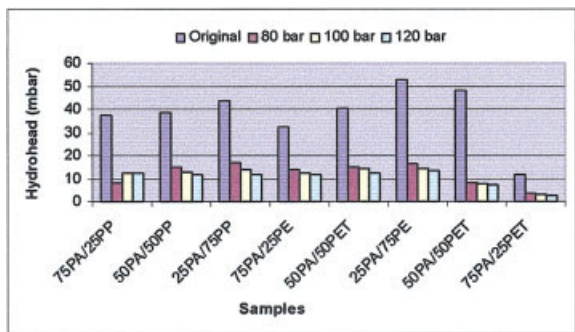


Figure 9 Hydrohead of bico webs before and after hydroentanglement.

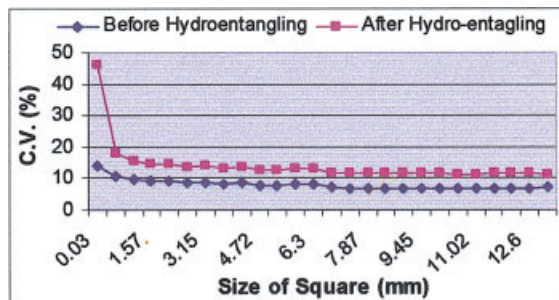


Figure 10 Web uniformity of 50PET/50PA6 bico meltblown web before and after hydroentanglement (100 bar).

only by the polymers' properties but also by the equipment parameters and processing conditions.

The effect of hydroentanglement on web properties varied with the processing conditions, bico composition, and original web structure. The posttreatment generally enhanced web softness and elongation. The fiber size was decreased for PP/PA6, PE/PA6, and PET/PA6 bico webs with partial fiber splitting by hydroentanglement.

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