New glass-fiber geometry—a study of nonwovens processability

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ABSTRACT

A recently developed bicomponent glass fiber (Miraflex™) shows promise as an alternative to synthetic fibers in nonwovens applications. The unique three-dimensional structure of this inorganic fiber simulates the crimp in polymeric fibers. This paper presents data from studies of three major textile processes (carding, needling, and air laying) that were conducted with this fiber. The results demonstrate that 100% glass fiber is truly cardable and can be processed on conventional textile equipment. The paper includes recommendations for specific equipment features and process parameters that were found suitable for processing this fiber.

Application:

Describes a cardable glass fiber with potential application in the manufacture of nonwoven products.

Glass, in its fibrous form, has been known since artisans first made glassware in ancient times. Fiberglass, available commercially since 1932 *(1)*, is used in a variety of important products. Two forms are commonly available: blown glass (wool) and continuous filament. The predominant application for blown glass is thermal insulation. Continuous filament is used in textile applications as spun yarn, woven fabric, or chopped strands.

A recently developed form of glass fiber offers unique opportunities for improved textile processing for new commercial applications, or as a substitute for higher-priced specialty fibers that are temperature resistant and fire retardant. This paper describes the new material and how it can be processed. The information should assist potential users in developing new applications to take advantage of this new form of glass fiber.

MIRAFLEX* FIBER

Miraflex is the trade name for a new form of glass fiber *(2)*. The product—a bicomponent fiber incorporating two glass formulations with different coefficients of thermal expansion—is formed using a proprietary glass-fusion technology. This process produces a fiber with a unique, three-dimensional geometry of irregular twists. **Figure 1** shows a typical fiber. **Figure 2** shows a cross-section of the bicomponent glass fiber.

Fiber physical properties are summarized in **Table I.** The fiber is fine diameter (7–8 µm) with a density of 2.46 g/cm^3. The typical ratio of stretched-to-relaxed fiber length, a measure of fiber geometry, is 2:1. The moisture regain of the fiber is <0.1% by weight. The open fiber assemblies have a very high sorptive capacity, up to 40 times their own weight. Since this is a type of glass fiber, it also offers value in high-temperature and fire-retardant applications.

*Miraflex™ is a trademark of Owens–Corning.

TEXTILE PROCESSING

With the emergence of any unique, new fiber material, a key question to be asked before developing applications is "How can this be processed?" Based on our knowledge of textile processing, we anticipated that the irregular shape of the newly developed fiber could provide many of the inherent processing advantages of crimp in a polymeric fiber. Because of the high fiber volume produced from this geometry, fibrous assemblies have excellent loft and recover readily from compression.

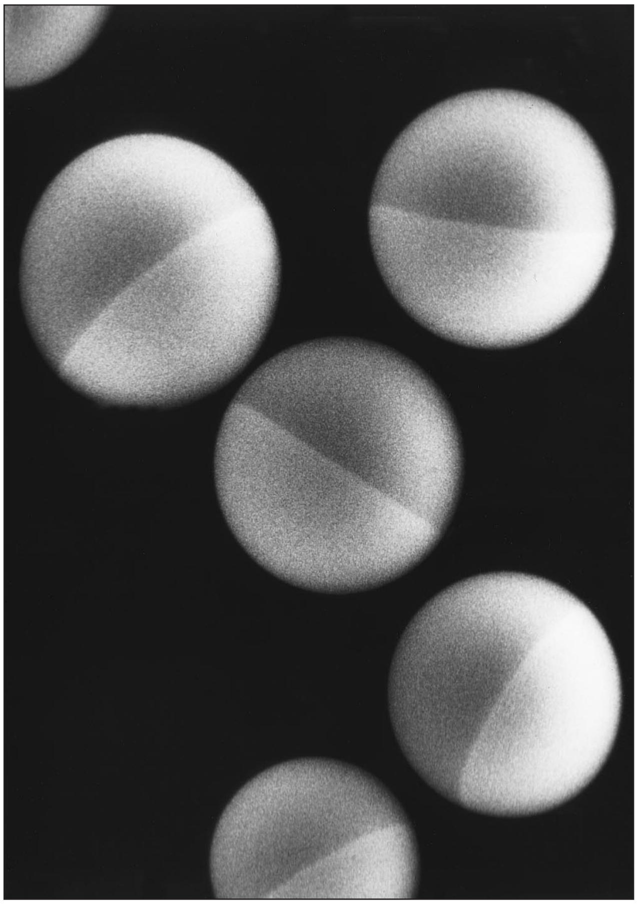
To evaluate the processability of this fiber, Owens–Corning and Albany International Research Co. undertook a joint research program to experiment on a variety of lab, pilot, and production textile processing equipment. This paper presents results for three major processes: carding, needling, and air laying.

Carding

Carding is the process of mechanically opening, combing, and aligning staple fibers into nonwoven webs. Carding equipment uses a series of rotating cylinders and plates covered with either hard metal or flexible wire. Carded webs are typically used to form nonwoven products or are the precursor form used to prepare spun yarns. The carding process can provide good-quality nonwoven webs of uniform fiber distribution. Carding is also an efficient method for producing well-mixed staple fiber blends. A range of nonwoven product weights can be obtained with a card by varying the weight of a single-layer carded web and by varying the way in which multiple layers are combined, or crosslapped, into batting *(3)*.

The cardability of a fiber depends on its geometry, frictional properties, mechanical properties, fiber diameter, and staple length. Crimp is particularly important for fibers to be processed through a card. Natural and synthetic fibers with crimp can generally be carded well with the appropriate selection of carding conditions. Conventional textile glass fiber, which lacks crimp, can only be

1. Model of fiber geometry



2. Fiber cross-section

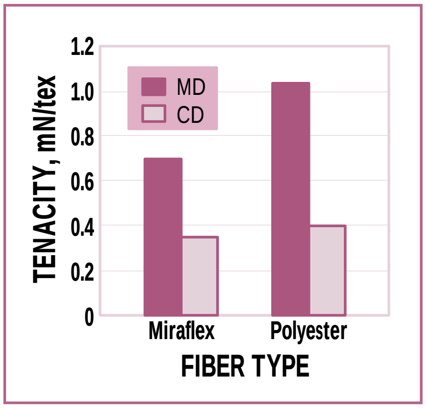
carded under limited conditions *(4)*. Conventional glass fiber requires a fiber chemistry designed specifically for carding, and in most cases it requires blending with polymeric fiber. This has limited its use in many applications.

To evaluate the carding performance of Miraflex fiber, a series of screening trials was conducted on a 12-in. (300-mm) single-cylinder, metallic, roller-top lab card (Davis and Furber). The trials indicated that uniform, cohesive webs of 100% glass could be produced without the addition of any carrier polymeric fiber. The product web was soft and lofty, showing good recovery when subjected to compression. These results confirmed that the three-dimensional geometry of the new fiber acts in a manner similar to crimp in a polymeric fiber.

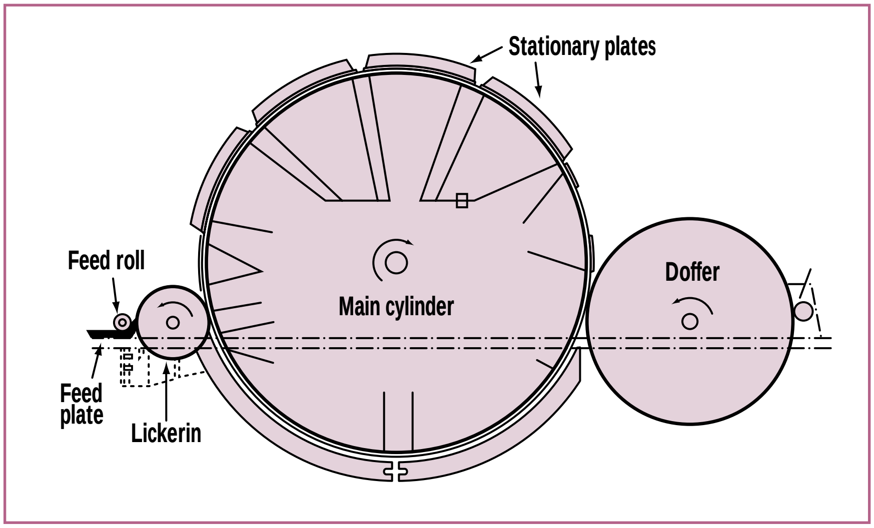
Following carding, web layers were combined and needled to produce a batt of 300 g/m^2. The 100% glass batts needled well and handled similarly to polymeric fibers. **Figure 3** compares the tensile properties of carded and needled samples consisting of 100% Miraflex fiber and 100% polyester fiber. The machine direction (MD) strength of the 100% Miraflex batt was approximately 67% of an equivalent polyester structure. With this encouraging result from laboratory samples, the challenge was to translate this behavior into production.

A series of experimental trials was conducted at Hollingsworth on Wheels, Inc., to assess the cardability of the fiber on production-scale equipment and to identify key design features that influence its cardability. A card with flexible design and variable speed control was used in these experiments (Cardmaster®). The 1-m-wide single-cylinder metallic card was equipped with four stationary plates. **Figure 4** shows a schematic of this style of card, which is commonly used in both the nonwovens and yarn industries and is well suited for short fiber. Because of the new fiber's openness and loft, we have found that it does not require extensive carding. In fact, a limited amount of carding with mild conditions is preferred. A single-cylinder card provided the necessary level of carding and produced uniform, cohesive webs while minimizing fiber breakage.

As a result of our work, we recommend the conditions listed in **Table II** for carding Miraflex fiber. Nonserrated wire should be used. The main cylinder should be clothed with short (2.5 mm), fine-gauge metallic clothing with a high number of points per square centimeter.



3. MD and CD tenacity of needled batts made of 100% Miraflex and 100% polyester



4. Single-cylinder, 40-in.-wide metallic card with four stationary plates

Physical properties	
Diameter, µm	7–8
Diameter coefficient of variation, %	37
Fineness (average), denier	1
Density, g/cm^3	2.46
Length ratio (stretched:relaxed)	2:1
Glass surface moisture regain (water, 22°C, 65% RH), wt.%	<0.1
Bulk-fiber-array sorption (water, unconstrained)	30–40 times its weight
Thermal and mechanical properties	
Tensile strength (single filament), MPa (10^3 psi)	689–1034 (100–150)
Young's modulus, GPa (10^6 psi),	67 (9.9)
Thermal conductivity at 22°C, W/m°C (Btu·in./h·ft^2°F)	1.045 (7.2)
Specific heat, J/g°C (Btu/lb$_m$°F)	
At 22°C	0.825 (0.197)
At 200°C	1.04 (0.249)
Softening point, °C (°F)	662–691 (1224–1275)
Strength retention at 315°C, %	50
Maximum continuous-use temperature, °C	450
Combustion	Does not support
Durability and resistance	
Water	Good
Acid	Fair
Alkaline	Fair
Solvent	Very good
Ultraviolet	Excellent

*The properties in this table are provided as guidelines for new product development and should be tested in the final product form.

*I. Fiber properties**

The gap at the feed roll should be fairly large (1.25–2.50 mm) to allow good fiber feed while minimizing fiber constraint. Short, medium-to-fine wire is recommended for the plates to prevent loading of the plates. The plate-to-cylinder gaps should be set with gradually decreasing gaps from the feed to the doffer (from 1.0 mm to 0.56 mm).

Using these conditions, production rates of 10–70 lb/h (4.5–31.8 kg/h) were achieved on the 1-m-wide card. Although higher production rates have not been attempted, we do not expect any problems in achieving at least a 20% higher production rate. Product quality and strength across the batt width were good. The fiber in the carded web maintained reasonably good average residual fiber length (≈25 mm).

Further detailed study of carding was conducted to identify variables important to batt quality and strength. A 2^3 factorial experiment was conducted using two carding production rates [30 lb/h and 50 lb/h (14 kg/h and 23 kg/h)], two fiber types (A and B), and two fiber manufacturing conditions (1 and 2). The responses measured were: batt uniformity, batt tensile strength, and modulus. The experimental design and results are shown in **Tables III and IV**, respectively.

At each of the experimental conditions, continuous carded, crosslapped, and tacked batts were formed and collected for testing and subsequent needling trials. The cross-machine direction (CD) uniformity of the crosslapped batt was measured by cutting and weighing 2-in. (50-mm) squares across the width at the beginning, middle, and end of the batt roll. **Figure 5** shows the CD basis-weight profile for a typical batt.

Tenacity and modulus, important to the handling and deformation of the carded, crosslapped batt, were measured on 3-in. x 10-in. (75 mm x

CARD PARAMETER	RECOMMENDED SETTING
Cylinder features	
Wire type	Nonserrated, metallic
Overall wire height	Short (<2.5 mm)
No. of points per unit area	High [>93 points/cm^2 (>600 points/in.^{2})]
Stationary plate features	
Wire type	Nonserrated, metallic
Overall wire height	Short
No. of points per unit area	Medium to high
Plate-to-cylinder gap	Gradually decreasing gaps from feed to doffer, 1.0 mm to 0.56 mm
Feed-roll-to-plate gap	Large (1.25–2.50 mm)

II. Recommended conditions for stationary plate card

Run no.	PRODUCTION RATE, kg/h	PRODUCTION RATE, lb/h	Fiber type	Fiber manufacturing conditions
1	14	30	A	1
2	14	30	A	2
3	14	30	B	1
4	14	30	B	2
5	23	50	A	1
6	23	50	A	2
7	23	50	B	1
8	23	50	B	2

III. Experimental design: production carding study

Run no.	Basis weight, g/m^2	TENACITY (CD) mN/tex	TENACITY (CD) mg/denier	MODULUS (CD) mN/tex	MODULUS (CD) mg/denier
1	221	0.47	5.4	20.2	229
2	221	0.29	3.3	14.0	159
3	201	0.22	2.5	10.4	118
4	236	0.17	1.9	12.2	138
5	240	0.43	4.8	19.1	216
6	244	0.39	4.4	15.4	174
7	231	0.22	2.5	12.3	139
8	224	0.13	1.5	8.1	92
Average	227	0.29	3.3	14.0	158
Range	201–244	0.13–0.47	1.5–5.4	8.1–20.2	92–229
Average main effects of test variables					
Production rate					
30 lb/h	220	0.29	3.3	14.2	161
50 lb/h	235	0.29	3.3	13.7	155
Fiber type					
A	232	0.40*	4.5*	17.2*	195*
B	223	0.19*	2.1*	10.8*	122*
Manufacturing conditions					
1	223	0.34*	3.8*	15.5*	176*
2	231	0.25*	2.8*	12.4*	141*

*Significant at the 95% confidence level

IV. Results of production carding study

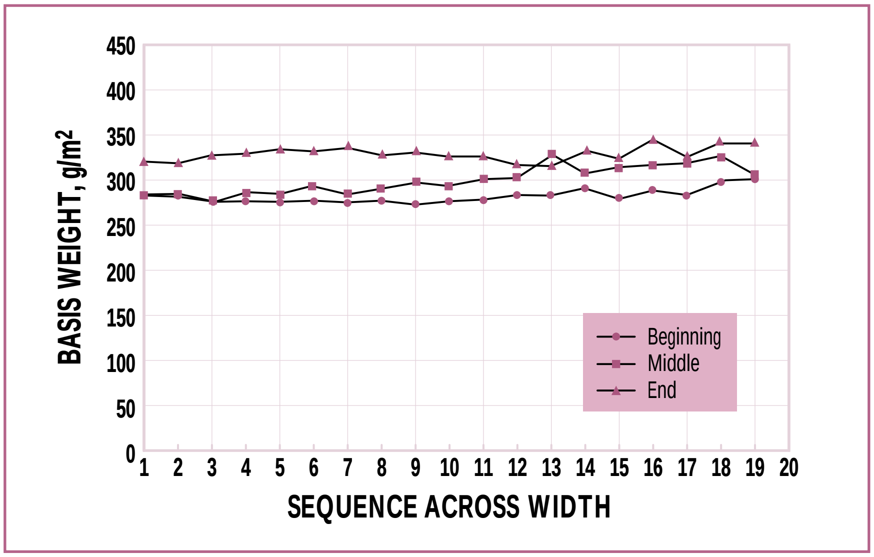
254 mm) strips cut in the CD. **Figures 6 and 7** show the tenacity of the carded, crosslapped batt as functions of fiber type and fiber manufacturing conditions, respectively. Clearly, both variables have a significant effect on batt tenacity.

Fiber A, which has a low-lubricity surface in comparison with Fiber B, produced a batt of significantly greater strength. Also, manufacturing condition 1, within the range studied, produced greater batt strength. Both results can be understood by considering two factors that influence batt strength: fiber length and fiber entanglement. Our observations suggest that the preferred fiber type should have sufficient uniform lubricity to minimize fiber breakage and maximize fiber length as the fiber progresses through the card. But the fiber type should not have such high lubricity that the fibers in the finished tacked batt can be easily pulled apart, reducing the strength of the fiber entanglements and overall batt strength.

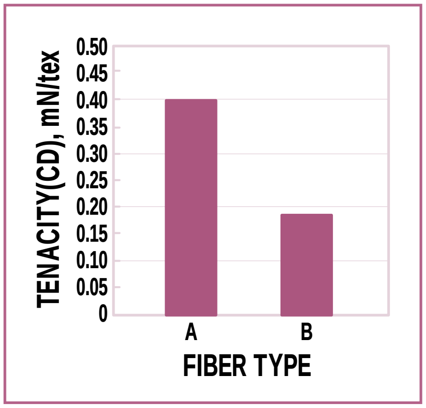
Production carding of the new fiber was also conducted on a 1.2-m-wide roller-top card. The single-cylinder card, equipped with six worker rolls and six stripper rolls, is shown in **Fig. 8**. The same design features that we recommended for the stationary-plate card also apply to the roller top. The main cylinder was clothed with a short, fine-gauge metallic wire with a high number of points per square centimeter. Serrated wire was not used on any of the rolls. The gaps from the workers to the cylinder and from the strippers to the cylinder were set to gradually decrease from the feed to the doffer. Web quality was very uniform, and crosslapped, tacked batts were collected and used to produce needled prototype fabrics.

Needling

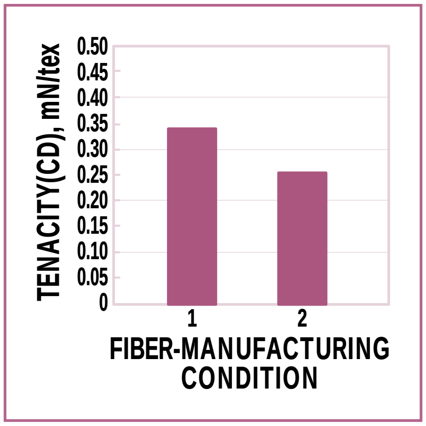
Needling, or needlepunching, mechanically interlocks fibers by repeatedly punching through the fiber batt with an array of barbed needles. Typically, needling is used to densify a structure, to improve strength, or to



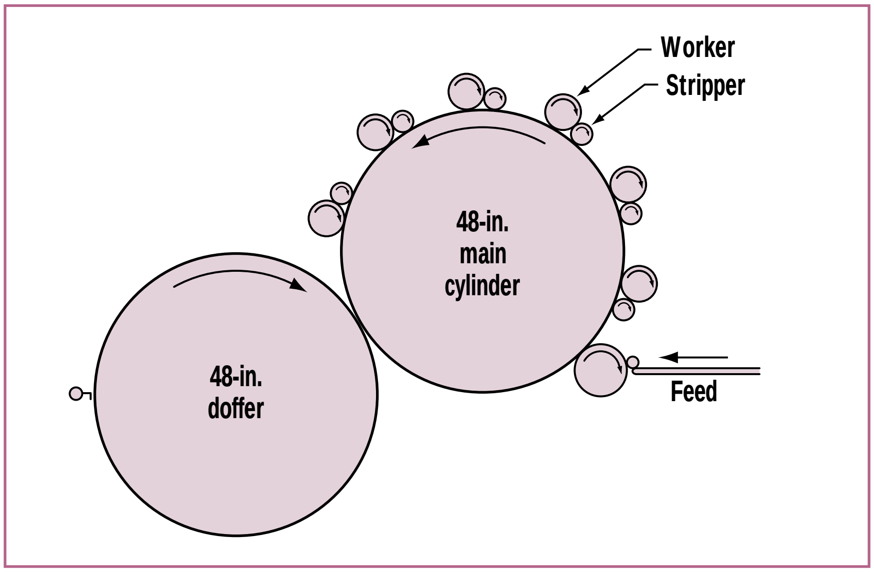
5. CD basis-weight profile of typical batt



6. Effect of fiber type on carded batt tenacity



7. Effect of fiber manufacturing conditions on carded batt tenacity



8. Roller-top card with six worker rolls and six stripper rolls

control porosity. Needling is a common method for producing such nonwoven products as filtration fabrics and industrial felts for a variety of applications. The structure produced by needling is controlled by manipulating process variables.

After our initial screening determined that an all-glass composition could survive needling with reasonably good product strength and appearance, we began to examine the needling process more carefully to determine how needling parameters affect the characteristics of the resultant product. To evaluate needling variables, a 2^3 factorial experiment was conducted to determine the effect of needle type, penetrations per unit area, and needle-board density. The experimental design is shown in **Table V**.

A production-size needle loom (Hunter) was used for these studies. Two types of needles were used: a coarse-gauge, aggressive, multibarb needle with a large barb volume (Groz Beckert 26) and a fine-gauge, nonaggressive, multibarb needle with a smaller barb volume (Singer 100). The total number of needle penetrations per unit area was set to either 500 or 1000 penetrations (pens) per square inch (pens/in.^{2}) [77 or 156 penetrations per square centimeter (pens/cm^2)]. This was accomplished by sending the sample through the loom for either two or four passes (250 pens/in.^{2} per pass). The needle-board density was set to either one-half or full board density. The one-half board density was achieved by removing every other row of needles in the machine direction. With the reduced board density, the number of needle penetrations per pass was held constant by reducing the fabric advance. The sample characteristics chosen to evaluate

Run no.	Needle type	Needle penetration, pens/in.^{2}	Board density
1	Aggressive	500	1/2
2	Aggressive	1000	1/2
3	Aggressive	500	full
4	Aggressive	1000	full
5	Nonaggressive	500	1/2
6	Nonaggressive	1000	1/2
7	Nonaggressive	500	full
8	Nonaggressive	1000	full

V. Experimental design: needling variables study

Run no.	Basis weight, g/m^2	TENACITY (MD), mN/tex	TENACITY (MD), mg/denier	Elongation (MD), %	Thickness,[a] mm	Maximum compressive stress,[b] kPa
1	200	0.43	4.9	15	8.3	21.8
2	144	0.34	3.9	13	9.7	20.2
3	232	0.44	5.0	24	7.8	22.0
4	171	0.32	3.6	16	10.1	18.9
5	240	0.28	3.2	21	11.6	18.9
6	194	0.19	2.2	20	11.9	15.2
7	252	0.33	3.7	26	10.7	18.3
8	216	0.32	3.6	24	10.7	15.7
Avg.	206	0.33	3.8	20	10.1	18.9
Range	144–252	0.19–0.44	2.2–5.0	13–26	7.8–11.9	15.2–22.0
Average main effects of test variables						
Needle type						
Aggressive	187[c]	0.38	4.4[c]	17[c]	9.0[c]	20.7[c]
Nonaggressive	226[c]	0.28	3.2[c]	23[c]	11.2[c]	17.0[c]
Needle penetration						
500 pens/in.^{2}	231[c]	0.37	4.2[c]	22	9.6	20.3[c]
1000 pens/in.^{2}	181[c]	0.29	3.3[c]	18	10.6	17.5[c]
Board density						
1/2	195[c]	0.31	3.6	17[c]	10.4	19.0
Full	218[c]	0.35	4.0	23[c]	9.8	18.7

[a] At 0.007 kPa, normalized to weight of 300 g/m^2
[b] Stress required to compress sample to 10 lb/ft^3 (163 kg/m^3)
[c] Significant at the 95% confidence level

VI. Results of needling variable study

the effects of varying needling parameters were: basis weight, thickness, MD tensile properties, and compression properties. Results of this study are shown in **Table VI**.

These initial studies show that fewer penetrations and a more aggressive needle result in a higher-tenacity needled product. The aggressively needled samples, on average, produced a needled-batt MD tenacity of 0.38 mN/tex, compared with 0.28 mN/tex for the nonaggressive needle, as shown in **Fig. 9**. The samples needled with 500 pens/in.^{2} produced a tenacity of 0.37 mN/tex, compared with 0.29 mN/tex for 1000 pens/in.^{2}, as shown in **Fig. 10**. Fewer passes and a larger needle appear to gather and entangle fibers effectively in the batt while minimizing the extent of fiber breakage. Fewer needle penetrations and a more aggressive needle also produce a needled batt that is more resistant to compression, as indicated by the higher maximum compressive stress required to compress the sample to a density of 163 kg/m^3 (10 lb/ft^3).

Development of needling conditions is ongoing. A recent study was conducted to identify the needle types and needling parameters necessary to obtain target densities within the range 2.0–7.0 lb/ft^3 (32–112 kg/m^3), as measured in the uncompressed, as-needled state. The excellent loft of this fiber makes the low-density range easy to achieve, so we have targeted our efforts at identifying the appropriate conditions to achieve high-density needled products.

Candidate needle types were evaluated during trials at Foster Needle. These studies examined two needle styles and two needle sizes. The two style needles were a four-apex Star blade (36 gauge) and a conventional, three-apex, high-density barb (HDB) blade (36 gauge). Both styles concentrate the barbs near the point of the needle. This reduces the operating zone on the working blade and allows for rapid product densification. The second needling parameter, needle size, was studied using two different size Star blade needles: 36 gauge and 25 gauge. Although the barb shape and number of barbs were the same for both needles, the depth of the barbs was different because of the difference in gauge. The barb depth for the 25-gauge needle was 0.005 in. (0.127 mm), compared with 0.003 in. (0.076 mm) for the 36-gauge needle. These needling conditions and results are shown in

Needle type	NEEDLE PENETRATIONS pen/cm²	pen/in.²	Depth of penetration, mm	Basis weight, g/m²	Thickness, mm	DENSITY kg/m³	lb/ft³	TENACITY MD mN/tex	MD mg/denier	CD mN/tex	CD mg/denier
36 gauge											
Star blade	109	700	5.0	908	8.0	109	6.80	0.306	3.47	0.500	5.66
High-density barb	109	700	6.5	879	8.0	105	6.62	0.345	3.91	0.513	5.81
25 gauge											
Star blade	70	450	4.0	902	7.8	116	7.23	0.675	7.64	0.964	10.92
	66	425	6.5	792	7.7	103	6.43	0.570	6.45	0.812	9.20

VII. Results for different needle types

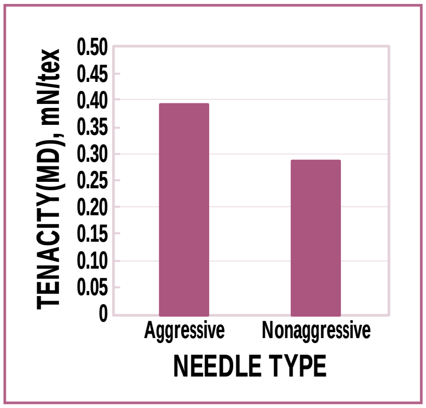
Table VII.

All three needles produced needled glass structures close to our density goal of 7 lb/ft³ (112 kg/m³), but there were no significant differences between the Star blade and the HDB. However, differences were measured between the two Star blade needles. The 25-gauge Star blade produced a slightly denser product, with almost twice the strength as that produced with the 36-gauge Star blade needle.

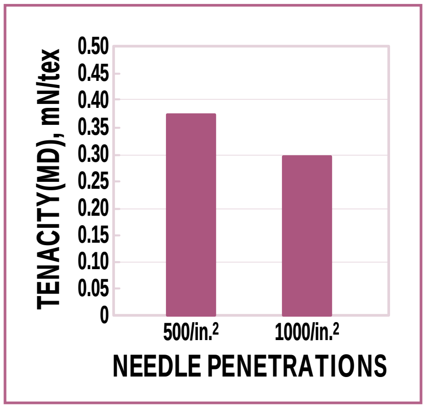
These results indicate that needles with a high-density barb configuration can convert 100% Miraflex fiber batting into strong, dense, needled products. Furthermore, these data confirmed results from our previous needle study, which showed that coarse, aggressive needles are preferred to finer-gauge needles with smaller barbs. With an aggressive needle, stronger products are produced because of the need for fewer penetrations and more efficient entanglement of fibers.

Air laying

Air laying is the process of separating, aligning, and depositing staple fibers into a nonwoven web using mechanical process rolls and controlled, high-velocity air flow. Tests were carried out on a commonly used commercial air-laid webber (Rando). The major components of the process are shown in **Fig. 11**. From the feeder section, the fiber is formed into a feed mat that passes between a feed plate and feed roll. The fibers are combed from the feed roll with a lickerin and introduced into the process air stream that forms the final web on a condenser screen. The Rando process is used to produce a variety of nonwoven products. It has the advantages of high production speeds and the ability to process a wide range of fiber types.



9. Effect of needle type on needled batt tenacity



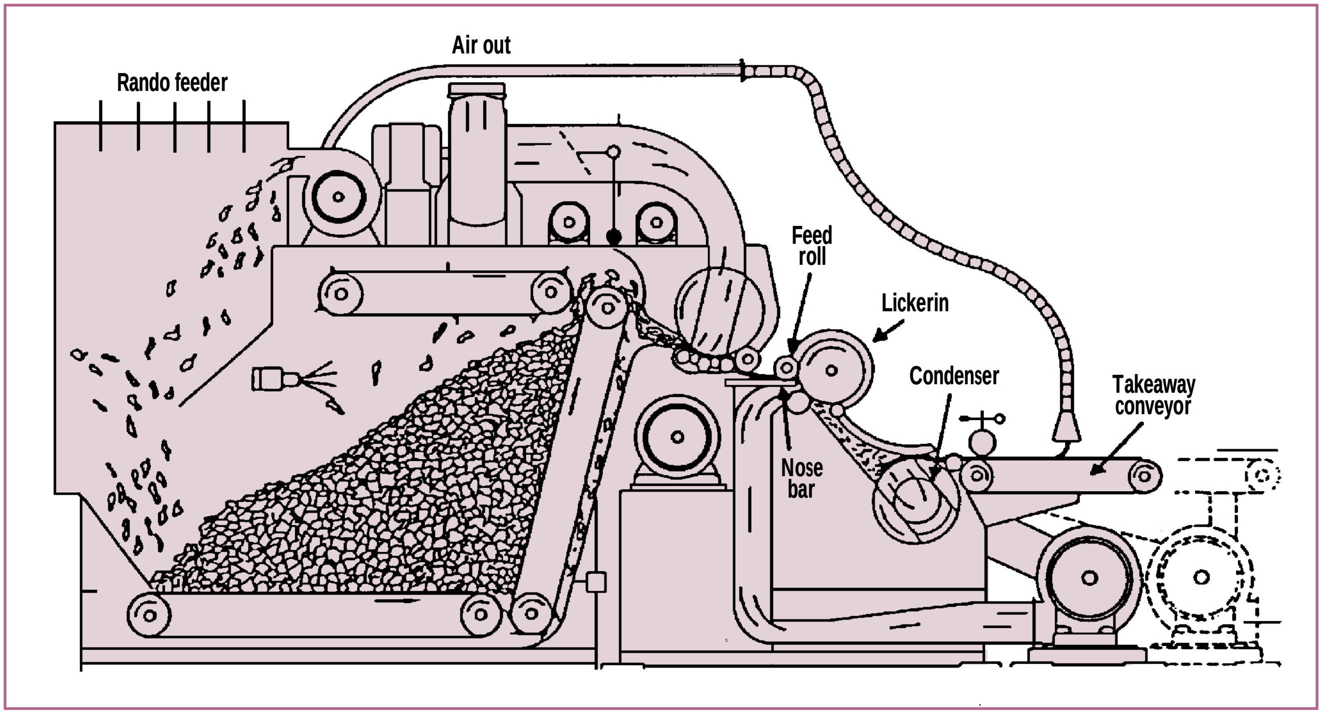
10. Effect of needle-penetration density on needled batt tenacity

The feasibility of processing the new fiber on an air-laid webber was evaluated in a trial (Rando Machine, Macedon, NY). The target goal was to produce a web that could be readily handled, sustaining a sufficient length by its own strength to be rolled, transferred, or subsequently processed. We were able to meet these goals by appropriate selection of machine configuration and settings. The recommended running conditions are summarized in **Table VIII**.

Because the fiber has excellent loft and recovery, we found that running the fiber through the prefeed and opener–blender was not required. Preferably, the fiber should be worked minimally, and should be fed directly into the feeder (Rando).

A variety of lickerin rolls can be used on the webber. We have found that acceptable web was produced with either the standard lickerin (5 x 8 x 8) or the optional (2.7 x 6), which is generally used for larger-diameter fibers. Speed setting on the lickerin was particularly important to web quality. If the speed was set too low, the web was clumpy and nonentangled. If the speed was set too high, the web was very weak with a high proportion of short, broken fiber ends. In the intermediate speed range (1500–1800 rpm for a 9-in.-diam. roll), a good quality web was formed.

The final edge of the feed plate holding the fiber mat against the feed roll is called the nose bar. Several nose-bar types are available. Our evaluations showed that a nose bar with a notched or sawtooth shape



11. Air-laid webber with split-air option

MACHINE PARAMETER	RECOMMENDED SETTING
Prefeeder	Not recommended [b]
Opener–blender	Not recommended [b]
Feed roll	Coarse wire wound
Feed-roll plate gap	0.44 in. (11 mm)
Nose bar	Shallow tight notch preferred (or tight notch)
Pinch point	0.012 in. (0.3 mm)
Lickerin feed gap	0.022 in. (0.56 mm)
Lickerin type	5 x 5 x 8 preferred, or 2.7 x 6
Lickerin speeds	1500–1800 rpm (9-in.-diam. roll) 1125–1350 rpm (12-in.-diam. roll)
Take-away conveyor	>8 ft/min (>2.4 m/min) [c]
Suction fan pressure	2 in. H_2O
Feeder fan pressure	3 in. H_2O
Updeck fan pressure	8–10 in. H_2O

[a] Rando-Webber™
[b] Direct feed into webber unless blending
[c] Lower speeds cause severe shingling

VIII. Recommended conditions for air-laid webber[a]

KEYWORDS
Air deposition, carding, deposition, fabric, fibers, glass fibers, inorganic fibers, man made fibers, needling, nonwovens, parameters, processing.

allows fibers to be combed out into the process air more readily that the smooth, rounded bar.

The web produced in these trials was in the range of 3.0–4.0 oz/yd^2 (100–135 g/m^2). Higher weights than this, with current setting guidelines, tend to produce a shingled structure. This occurs as the heavy fiber mat begins to lay up in a more vertical direction. A shingled structure should be minimized if the product is to be subsequently needled. Heavier needled structures can be achieved by combining lighter web layers.

For better fiber handling, the newer, split-air option on the webber is preferred. With this configuration, the air stream that carries the fibers from the lickerin is controlled separately from the air stream that pulls the fibers down onto the web condensing screen. The split-air option allows for filtration and removal of small fiber fragments circulating in the air stream, resulting in a cleaner system with better web quality.

CONCLUSIONS

Miraflex fiber—a bicomponent glass fiber with a three-dimensional geometry of irregular twists—can be processed effectively by conventional textile processing equipment. The fiber can be carded, needled, or air laid at 100% glass levels without the addition of polymeric fiber. Webs produced on production-scale equipment showed good strength and uniformity. The fiber handles in many ways similarly to a polymeric material. It is soft and lofty, with good compression resistance and recovery, and has excellent thermal stability and flame resistance. The processability of this new glass fiber should open up new applications in areas currently dominated by synthetics. The new fiber offers an interesting alternative to synthetic fibers and could be a cost-effective option in high-performance nonwovens applications. **TJ**

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