2004 BELTWIDE COTTON CONFERENCES, SAN ANTONIO, TX – JANUARY 5-9

DETERMINING FIBER ORIENTATION IN NONWOVENS BY DIGITAL QUANTIFICATION OF MICROSCOPIC IMAGES

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Abstract

Measurement of physical properties of nonwovens can be difficult. Strength parameters, for example, are different in nonwovens and in woven fabrics. Strength in woven fabrics depends on several factors. Measurement of strength is generally made in two directions, the warp and fill, of the fabric because the yarns are oriented in perpendicular directions. Strength and dimensional stability are thus greater in directions of the warp and fill yarns, and not on the fabric bias. Fibers in many nonwoven fabrics are not highly oriented but lie in many different angles in the plane of the fabric. Although nonwoven fabrics may be engineered for specific use and thus with intended fiber orientations, strength measurements are more difficult than in woven fabrics. With nonwovens blended of more than one fiber type, fiber order may become even more random, depending on the nature of the blend of the fibers. It thus becomes difficult to consistently determine the strength of the fabric since degree of fiber orientation is not certain. When a product of specific strength is needed and natural and synthetic fibers are blended, determination of fiber orientation can be of great importance. This work describes exploratory use of a procedure for determining degree of fiber orientation within nonwovens in any given direction. A computer program has been used to assign pixel grey-value increments to angles from 0 to 359^{o} in an image of a nonwoven surface. Pixel orientations are grouped in 1.4^{o} segments, and the data giving the counted pixel grey value within that angle can be grouped into any angle range. The percentage of pixels within a given angle range represents the fiber segments oriented at that angle. The procedure has been applied to several nonwoven fabric patterns, and data evaluated to determine whether fiber orientation measurements could be discerned successfully in fabrics of various fiber orientations using this method.

Introduction

Because of the long history of processing and quality measurements in woven fabrics, the same measurement parameters tend to be applied in the development and testing of nonwovens. Unfortunately, the same criteria may not always apply to nonwovens as to wovens. For instance, strength measurement in woven fabrics is directional, and breaking strengths are measured either in the warp or fill directions because of the directional orientation of the yarns. Because fibers in nonwovens generally do not have specific group orientation, the same type breaking strength measurements as used in woven fabrics are not useful. Figure 1 compares a woven and a nonwoven fabric. Although some processes for producing nonwovens provide some fiber direction, fibers are often laid down in random order. Direction, thus, can only be estimated by visual examination. If more than one type fiber is blended in a nonwoven, fiber orientation may fluctuate. When one of the blended fibers is cotton, fiber orientation and strength measurement become even more important. In general, cotton fibers are shorter and contribute less strength than most synthetic fibers in a blend. Well-distributed fiber orientations minimize strength losses in any given direction. Microscopic examinations of nonwovens give a general idea of fiber orientation and of degree of blending when more than one fiber type is used. However, these evaluations are subjective. A more objective approach to determining fiber orientation is to use image analyses of a microscopically generated digital image of the sample. There are many analysis programs that could perhaps be applied to this problem, however, the system that we are pursuing is Fovea Pro, and has been developed by Dr. John Russ, NC State University, as a plug-in system for other graphic arts programs. We are using the program in Photoshop.

In this paper we will not attempt to explain the very technical details of how the program works, but to show the basic principals, and how we have begun to apply the technique to some simple nonwoven structures to determine fiber orientation. There are a number of difficulties in the application, but these will be addressed later.

To visualize how this program works it is necessary to understand basic digital image formation. Digital images are formed by combining small "separate image detail elements" of varying shades of grey or in different colors. These picture elements are called "pixels". The number of these pixels per inch of image determines the amount of detail or resolution of the image. The greater the number of pixels per inch, the higher the resolution of the image becomes. Numbers of pixels in digital images can vary greatly.

The greater the number of pixels per given area in a digital photograph, the higher the resolution, or clearer the image will be. In Figure 2, a higher magnification of an image of a fiber having a low pixel count is shown, and individual pixels can be seen clearly. On the right a fiber image with high pixel count provides higher resolution and a more detailed image.

In digital images, pixels define the edges of objects and have directionality. Theoretically, counting of pixel edges oriented in a given direction would indicate quantities of edges in that orientation. In the program used for these measurements, the Sobel orientation function assigns values from 0 to 255 to divisions that represent angles from 0 to 359°, and also color codes, or grey-scale codes each pixel with the direction of the brightness gradient. Angles are normally measured from 0 to 359°. Therefore, each division in the pixel grey orientation values represents 1.4°. A histogram can show counts of the number of pixels with each grey value. It is of visual interest that color hue values also vary from 0 to 359° (red through magenta). Therefore, assigning the pixel value from orientation to the associated color provides direct representation of edge direction in color. Figure 3 shows fibers from a nonwoven fabric with colorized edges, indicating variations in fiber orientation as indicated by variations in color. It should also be noted in this image that opposite sides of each fiber are different colors since pixels on one side have gradient directions that are opposite to those on the other side. If data is collected from 0 to 359°, the histogram will have two complementary peaks that are 180° apart. This directional difference has to be taken into account in analyzing the data to prevent equal orientation values in opposite directions, or special processing can eliminate the duplication.

Application

To test the application of this technique to determining fiber orientation in nonwovens, a polypropylene nonwoven with visual vertical orientations was selected. Scanning electron micrographs were made of the sample at several magnifications, and one was chosen for digital image analysis (Figure 4).

Application of the program to this image produced a data sheet that indicates the number of pixels oriented in the direction of each 1.4° increment. Data was imported into Excel for manipulation. A histogram of pixel values can be displayed to show preferred orientation peaks of the fibers in the sample (Figure 5). The spikes that appear in the histogram every 45° occur because the image consists of an array of square pixels, and the contribution of the pixels along the edges of the image produce the spikes. They are generally ignorable side effects, and in practice serve as useful scale markers for the plots.

Table 1 shows how this data appears when presented as values for each angle. The number of pixels for each pixel value from 0 to 255 is provided in the program, but only representative values are given in the table because of space limitations. The first column is the assigned number for each pixel grey value (orientation increment). The second column shows the angle value in degrees, the third column represents the number of pixels from fibers oriented at that angle, and the fourth column the percent of pixels with that value.

Because no fiber edges are aligned completely straight, in order to cover the range of deviations from any given line, pixels covering a 40° range of each direction of interest were summed (Table 2). With this summation, in the sample used for this illustration, the greatest percent of fibers (20.08%) lie within a 20° range on each side of 90°. In the program, grey pixel counts indicate the number of pixels in each angular division. Because the histogram has two complementary peaks (Figure 5), approximately 20% of the fibers are shown to be at gradient directions 180° in the opposite direction. Therefore, on a percentage basis, more than 40% of the fibers in the image actually have a preferred orientation within 20° each side of vertical.

To further check the applicability of this system to measuring orientation of fibers in nonwovens, we rotated the image 90° and displayed it with the original image (Figure 6).

In this double image the same fibers are oriented both vertically and horizontally. A bar graph showing percentage of pixels grouped within 40° of selected angles from 0 to 315° is shown in Figure 7. Data show the lowest fiber orientation in the vertical image to be at 0 and 180°, and the highest at 90 and 270°. The opposite results were found for the horizontally oriented image. Thus, the pixel gradient orientation results correlate well with visual observations.

Application of this program to several different types of nonwovens has been carried out. Examples show how the program can determine fiber orientation. A sample that showed well-distributed fiber orientations is illustrated at two magnifications by a melt blown nonwoven containing 50% cotton (Figure 8). The table of pixel values summed over each 45° interval (Table 3) shows values to be relatively equal. The histogram of these values shows a periodic grouping of fibers over the whole sample surface (Figure 9). A helpful visualization of preferred fiber orientation can be seen if the pixel values are plotted in polar coordinates (Figure 10). The geometric shape of the plot for values obtained from this sample shows generally isotropic orientation.

By contrast, another melt blown sample containing 65% cotton appears directionally oriented (Figure 11). The fiber orientation histogram shows wide variations in orientation, with the highest pixel distribution grouped around 135° (Figure 12). A bar graph of these values shows the highest orientation to lie at this 135° angle as well (Figure 13), and the polar plot (Figure 14) indicates that the fiber orientation is not isotropic.

One problem in analysis of digital micrographs is that the micrograph images are two-dimensional and the specimen is three-dimensional. It is not possible to image fibers in nonwovens from upper surface to lower surface in a micrograph. Digital analyses are only carried out on fibers that can be imaged on the fabric surface. We attempted to counter this problem by imaging both sides of a fabric and comparing fiber orientations in the micrographs. Three areas of each side were analyzed. Six images, 3 each back and front, are shown in Figure 15. Orientation results were compiled on a bar graph (Figure 16). Though orientation values varied somewhat among samples, the variations were usually only a few percentage points, and the graph shows that high and low orientation values are generally comparable at the different sampling areas on both back and front of the fabric.

Conclusions

Determination of fiber orientations of nonwovens is not simple. Many nonwoven products are engineered to have predetermined structures, and are intended for specific uses. It is difficult to determine fiber orientation in the final product. Microscopic examinations provide the best visual means for studying fiber orientation but these are subjective. Digital analyses of micrographs offer a possibility of quantifying fiber orientation. The Fovea Pro program was applied to a group of micrographs of nonwoven surfaces to determine whether the data generated was supported by the visual information in the micrographs. Various configurations were used that indicated that the digital quantifications were measuring fiber orientations as shown in the micrographs. Selected samples were used to determine that digital measurements could provide data to characterize samples as having well distributed fiber orientations or fibers that were highly oriented in a given direction. The problem of thickness in samples was addressed by using micrographs from back and front sides of the fabric to determine whether the orientation data generated was applicable throughout the fabric rather than just to a surface. With thick samples it may be necessary to separate fabrics to obtain orientation data from inside the structure. In the data produced by all samples, pixel counts at various orientation increments were imported into Excel in order to manipulate the data to provide orientation percentages in a given direction and to generate plots and graphs. The generated data appears to provide the information needed to subjectively characterize directional orientation of fibers in nonwoven products. A further application of the technique could be to show changes in fiber alignment after physical deformations such as stretching or twisting.

Acknowledgments

Authors thank Dr. John Russ for help in applying the program to the samples and Dr. D. V. Parikh for supplying the nonwovens.

Note

*Fovea Pro v.3 program available through Reindeer Graphics, Inc.

Table 1.

Pixel Value	Angle (deg)	Pixels	%
0	0.00	9274	0.84%
1	1.41	1583	0.14%
2	2.81	1945	0.18%
31	43.59	1070	0.10%
32	45.00	10647	0.97%
33	46.41	2768	0.25%
63	88.59	5274	0.48%
64	90.00	13793	1.25%
65	91.41	7701	0.70%
95	133.59	10609	0.96%
96	135.00	830	0.08%
97	136.41	2133	0.19%
127	178.59	494	0.04%
128	180.00	5719	0.52%
129	181.41	1645	0.15%
159	223.59	967	0.09%
160	225.00	10434	0.95%
161	226.41	2607	0.24%
191	268.59	5312	0.48%
192	270.00	13792	1.25%
193	271.41	7588	0.69%
223	313.59	10047	0.91%
224	315.00	770	0.07%
225	316.41	1787	0.16%
254	357.19	1471	0.13%
255	358.59	5633	0.51%

Table 2. Pixel Count in 40^0 Increments.

Pixel Value	Angle (deg)	Pixels in 40 deg	%
0	0	73313	6.66%
32	45	117362	10.66%
64	90	221185	20.08%
96	135	100549	9.13%
128	180	65260	5.92%
160	225	114665	10.41%
192	270	219879	19.96%
224	315	91511	8.31%
		1003724	91.13%

Table 3. Chart of Pixel Values Summed Over Each 45^0 Interval.

Pixel Value	**Angle (deg)**	**Pixels in 40 deg**	**%**
0	0	0	0.00%
32	45	1688991	10.44%
64	90	1714741	10.60%
96	135	2055146	12.70%
128	180	1955534	12.09%
160	225	1819633	11.25%
192	270	1647687	10.18%
224	315	1875476	11.59%

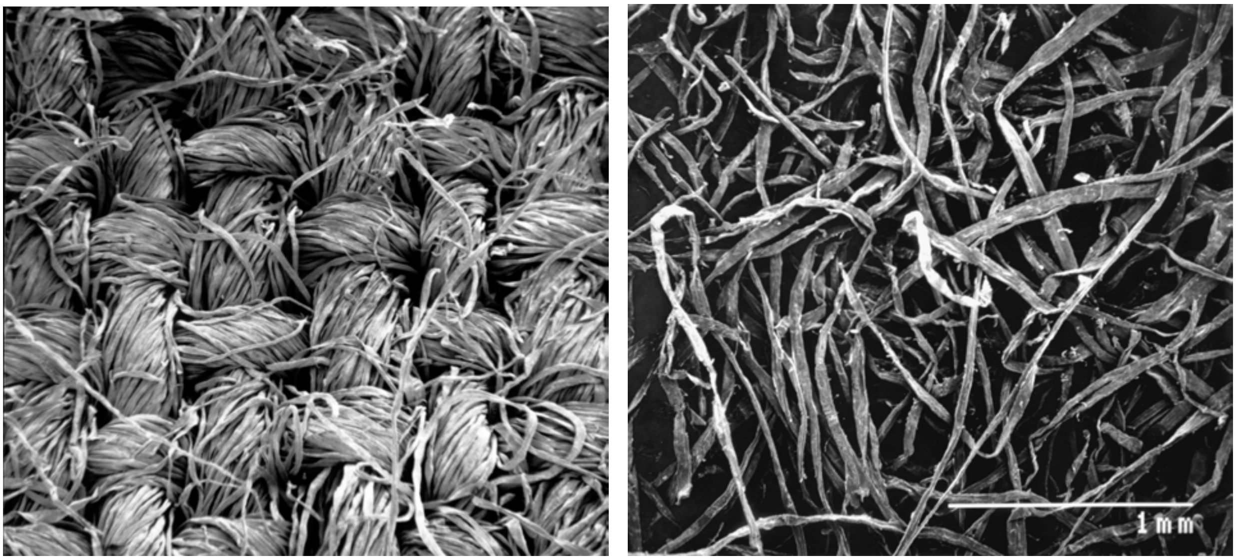

Figure 1. Woven and Nonwoven Fabric.

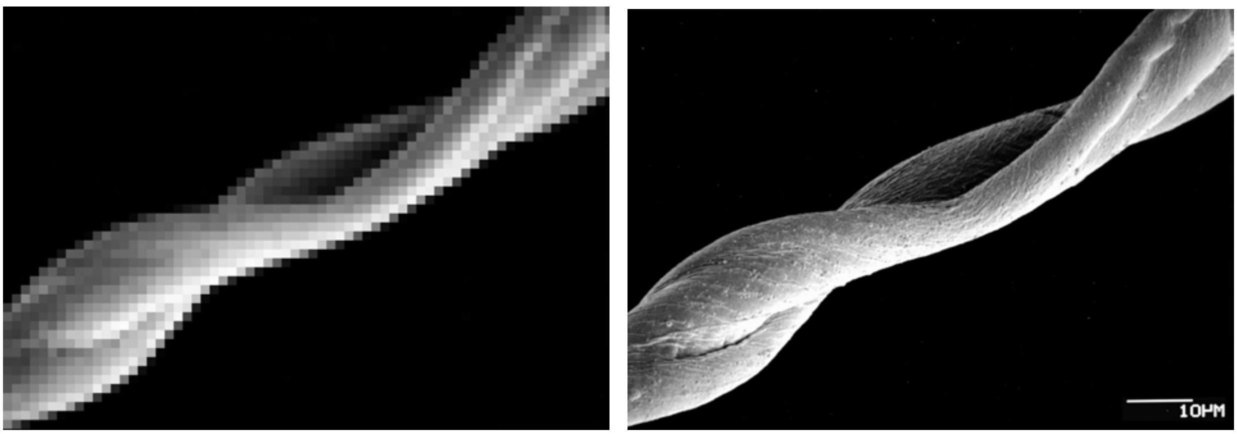

Figure 2. Low Pixel Count and High Pixel Count SEM Image of Fiber.

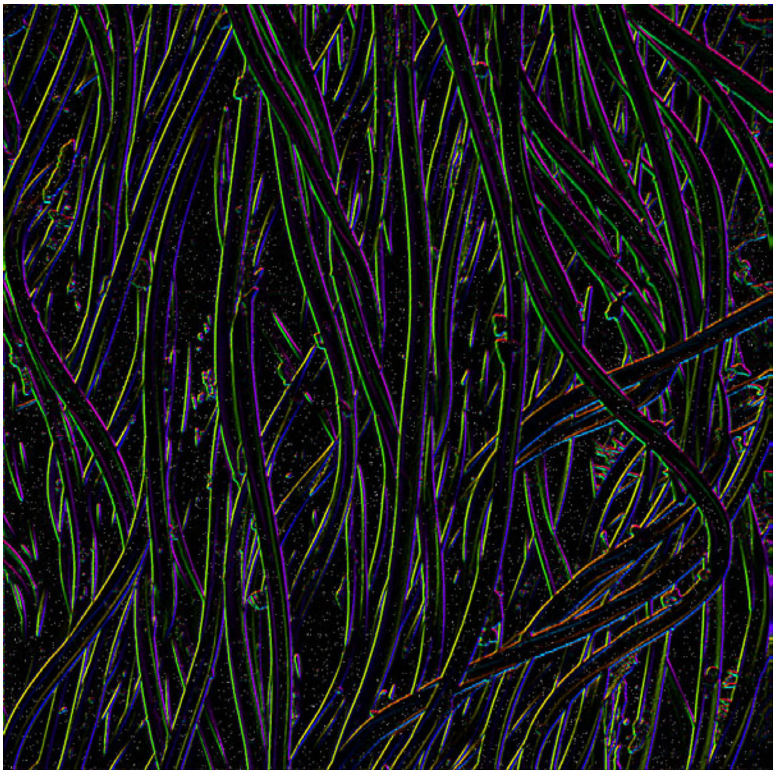

Figure 3. Sobel Orientation Showing Colorized Edges to Indicate Variation in Orientation.

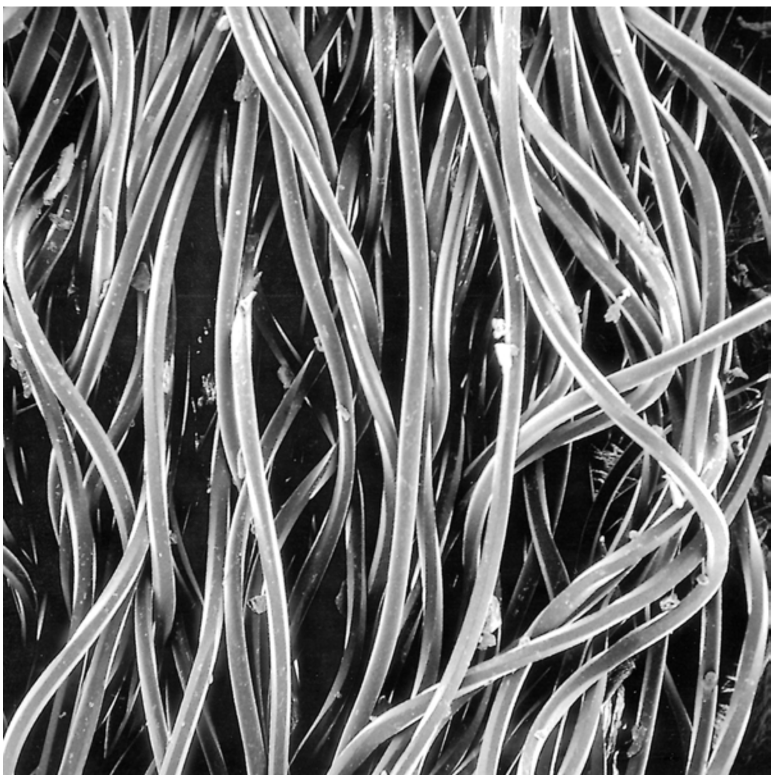

Figure 4. Polypropylene Nonwoven with Visual Vertical Orientation.

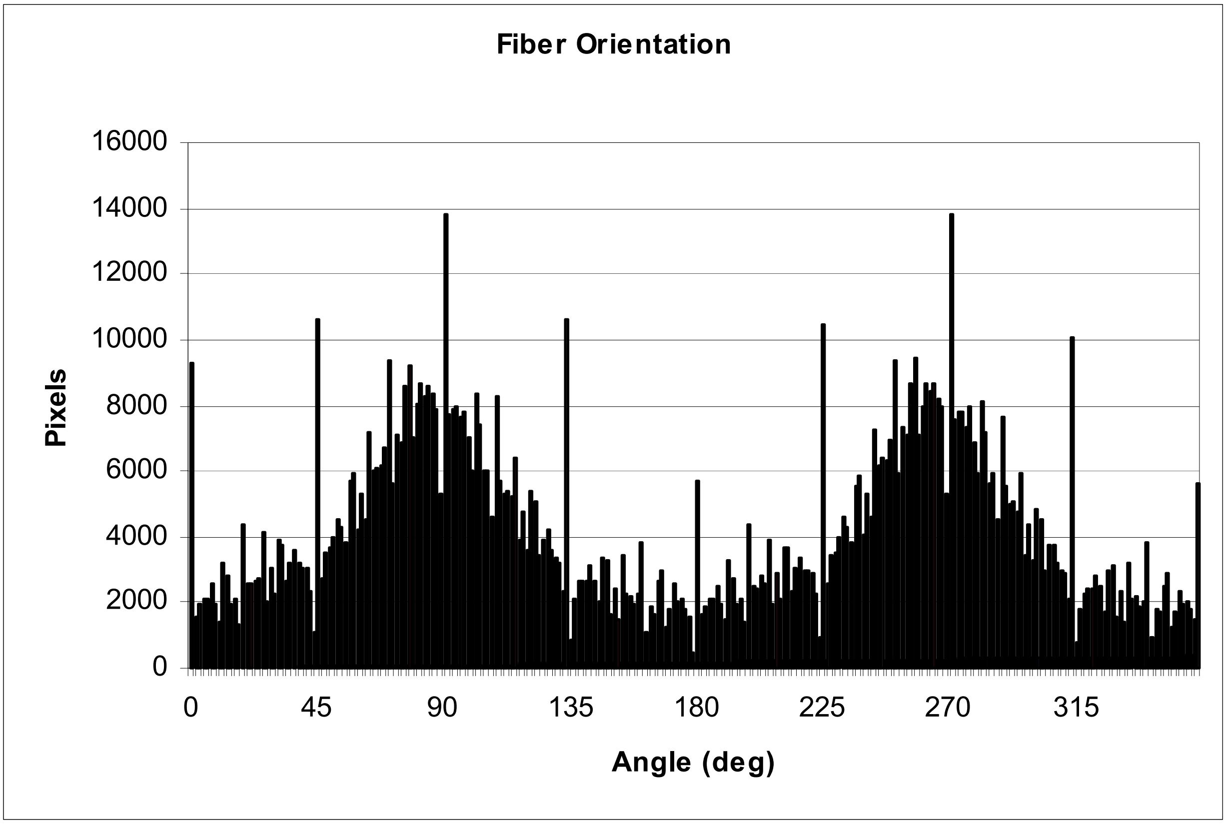

Figure 5. Histogram of Pixel Values Showing Preferred Orientation.

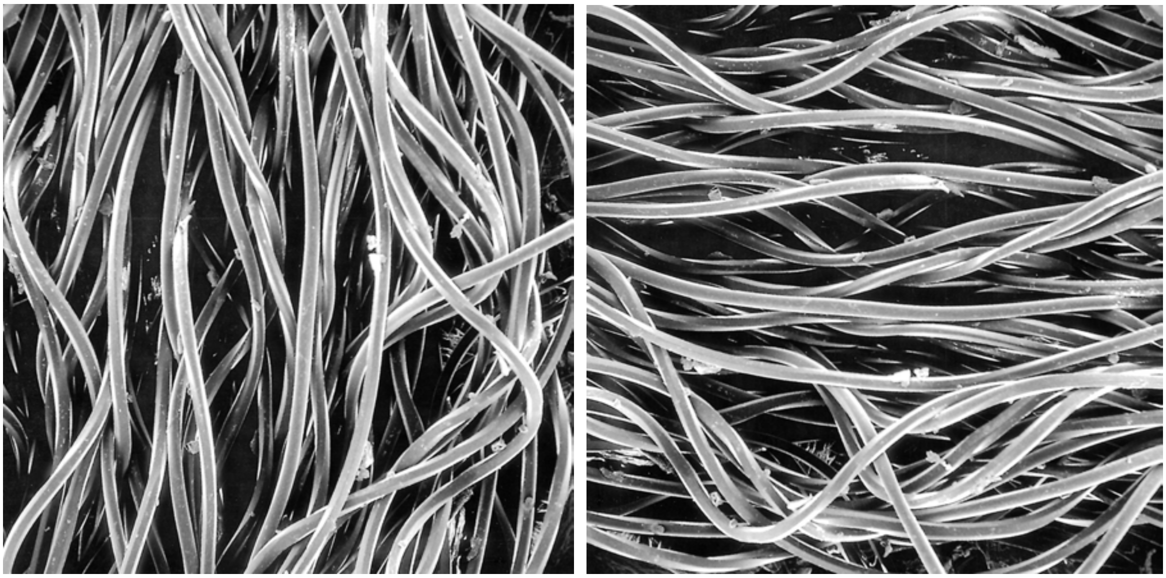

Figure 6. Vertical and Horizontal Orientations of an Image.

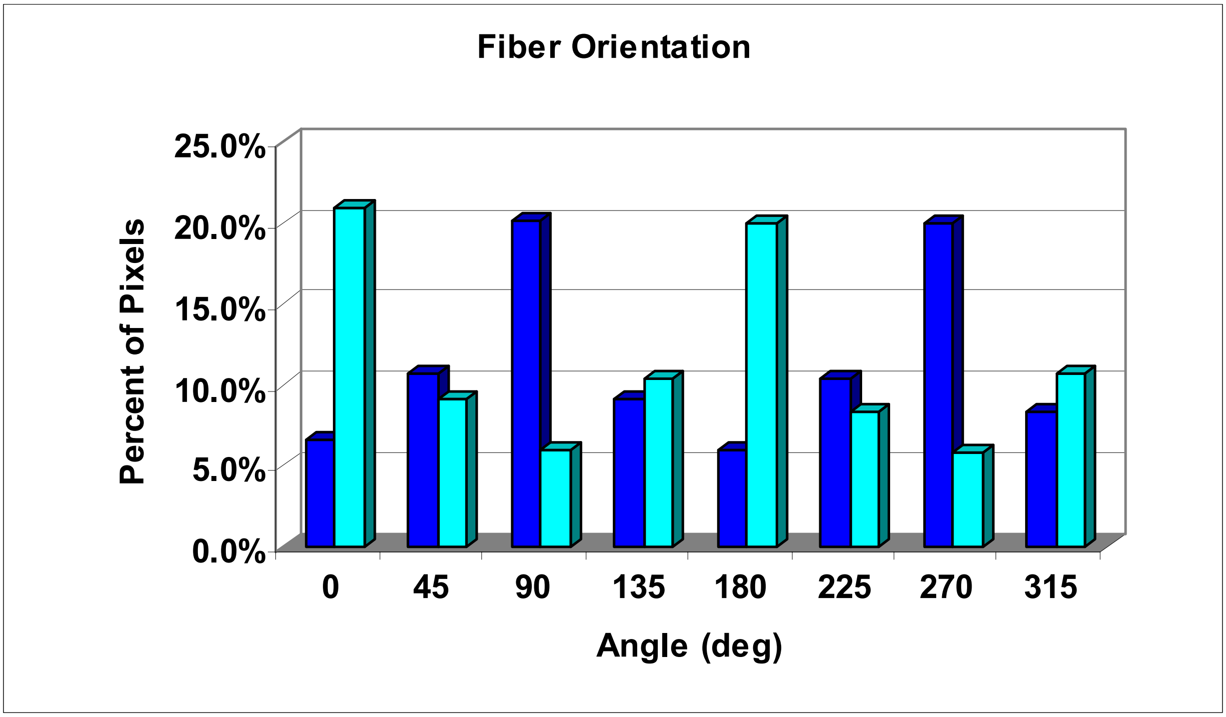

Figure 7. Bar Graph Showing Orientation Values Rotated 90^{0}.

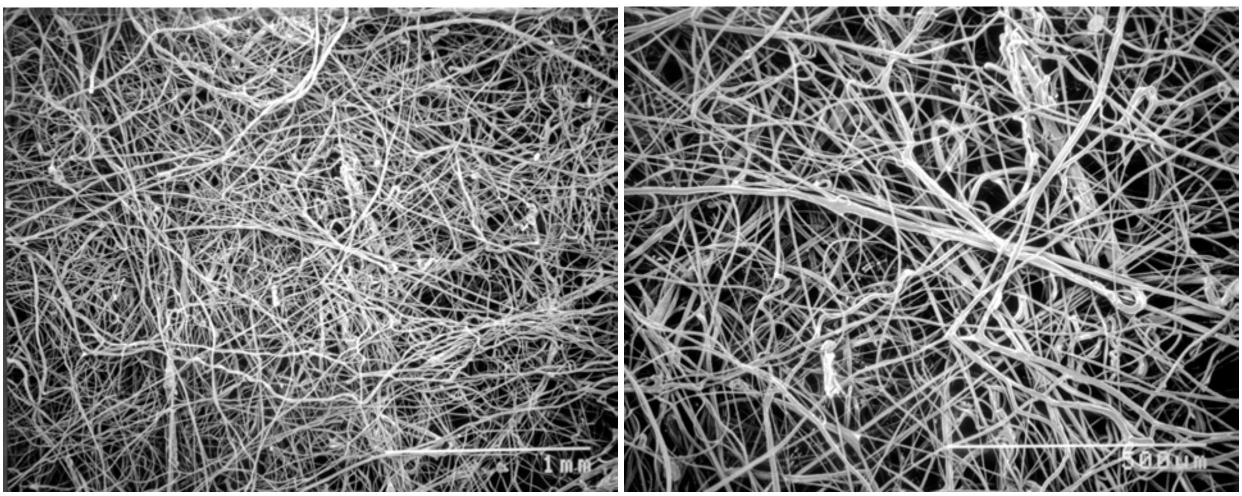

Figure 8. Melt Blown Nonwoven Containing 50% Cotton at Two Magnifications.

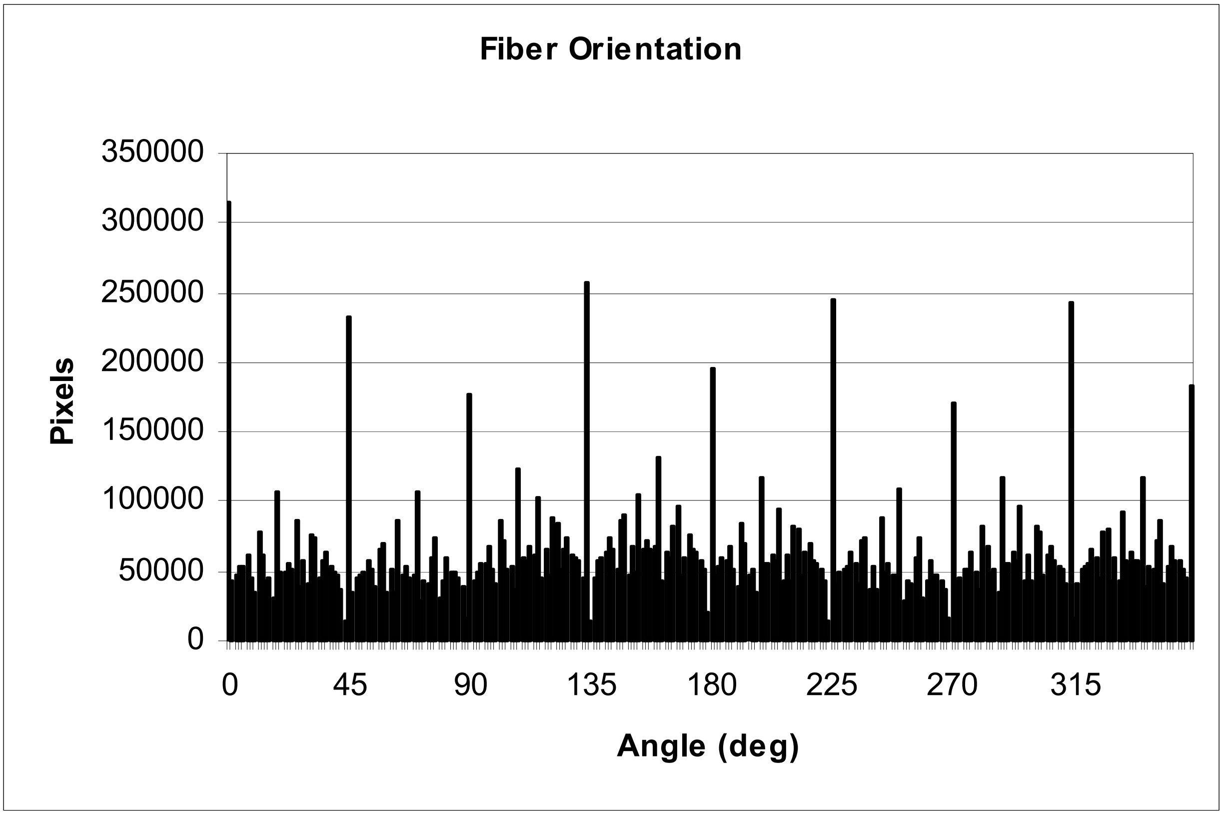

Figure 9. Histogram Showing Periodic Grouping of Fibers Over Sample Surface.

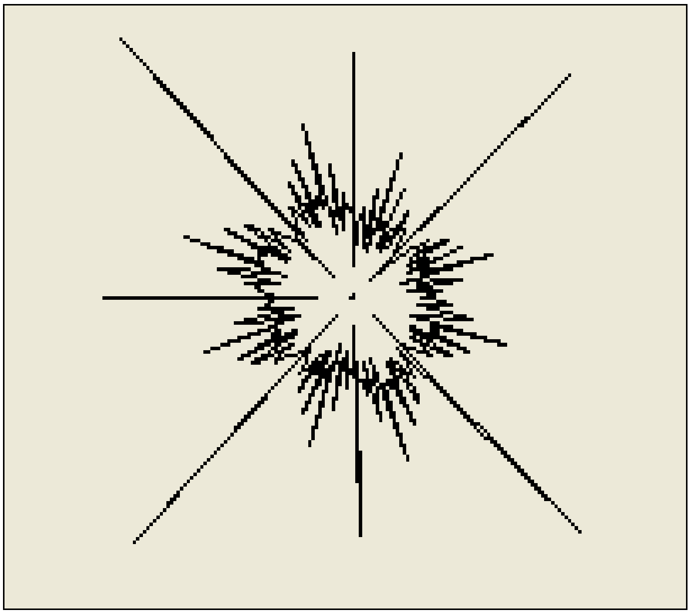

Figure 10. Polar Histogram of Image.

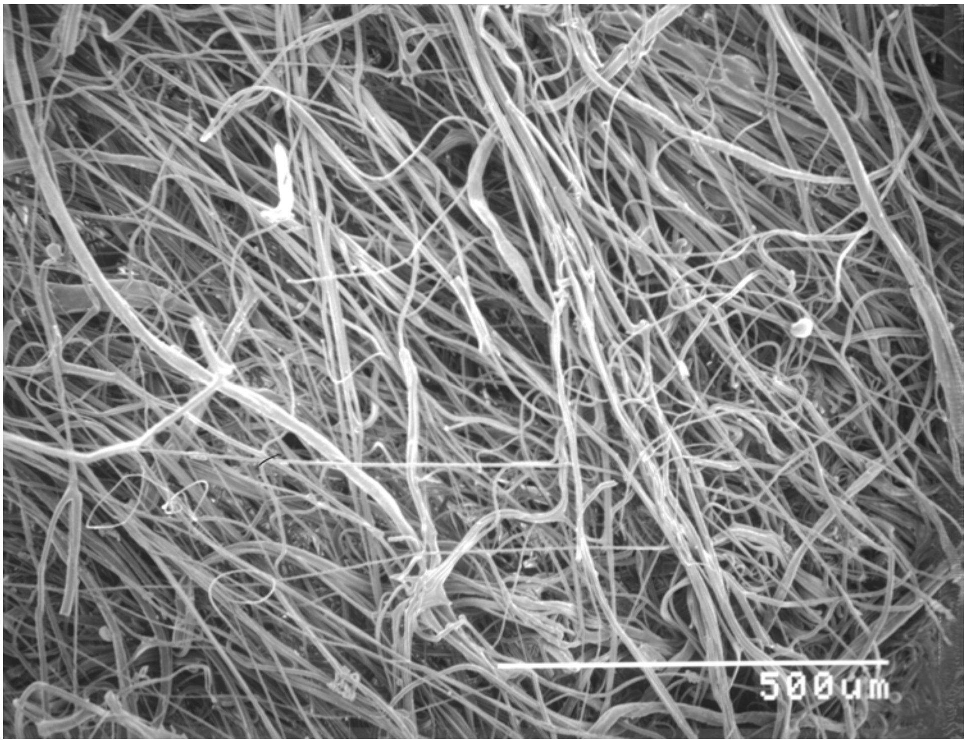

Figure 11. Melt Blown Nonwoven Containing 65% Cotton.

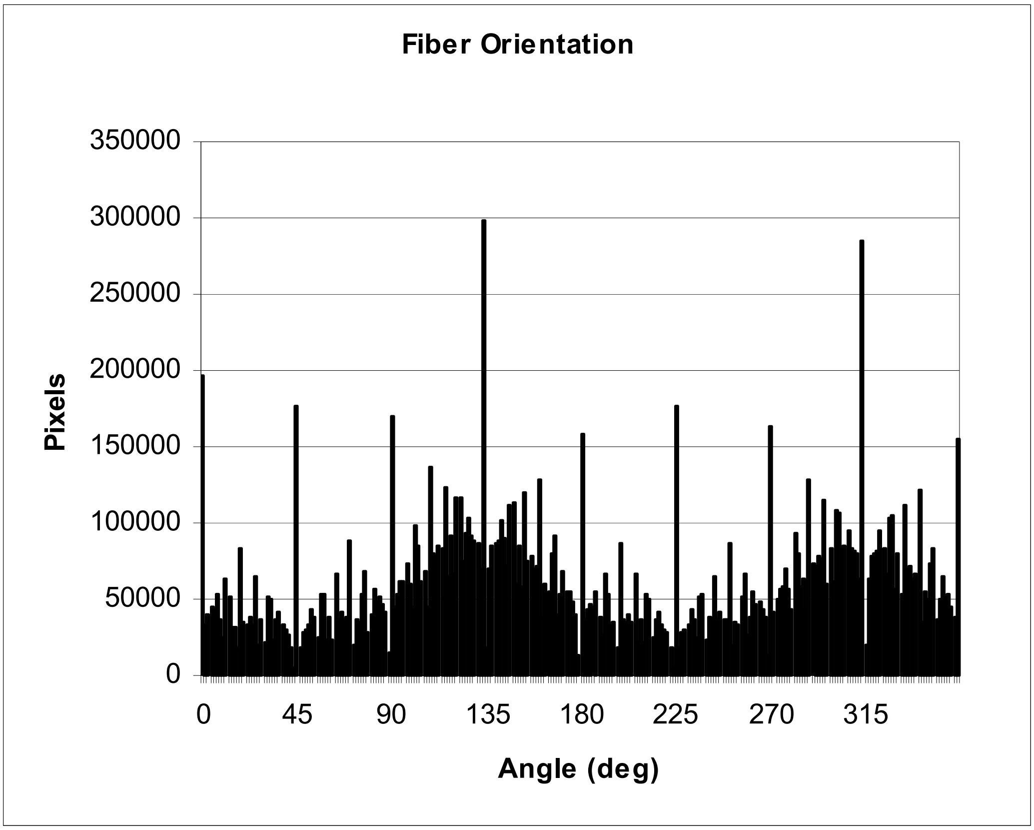

Figure 12. Fiber Orientation Histogram Showing Wide Variations in Orientation.

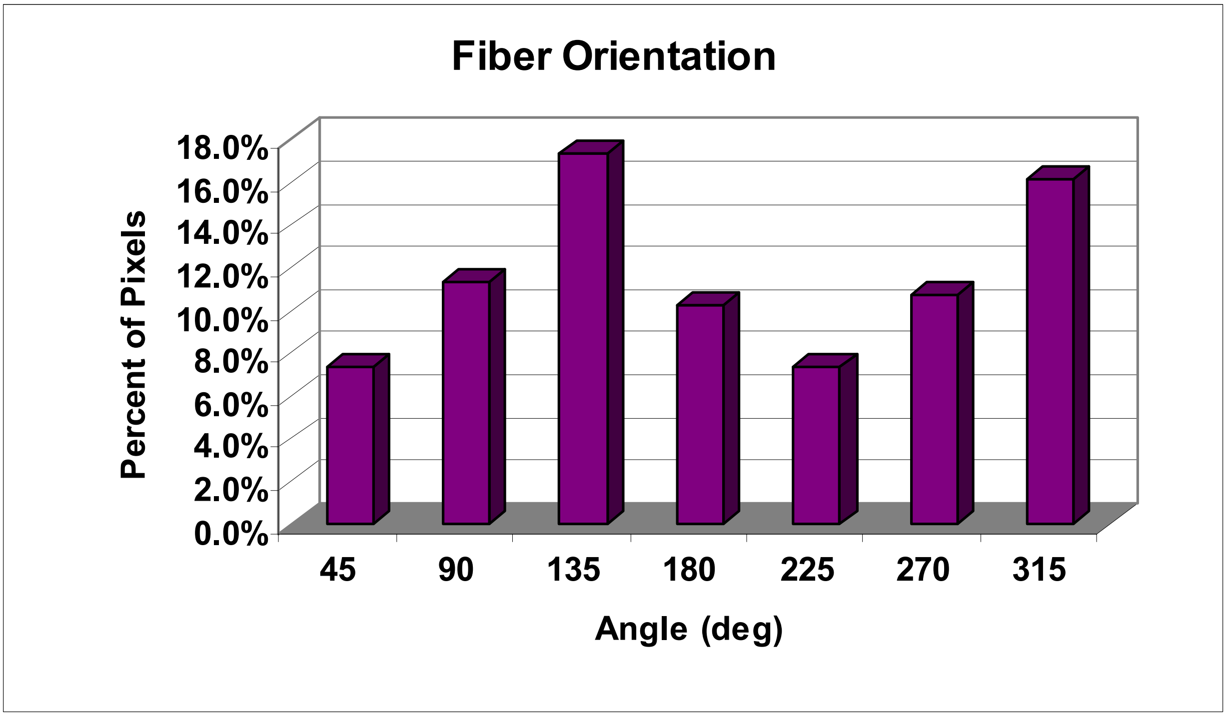

Figure 13. Bar Graph of Grouped Pixel Distribution.

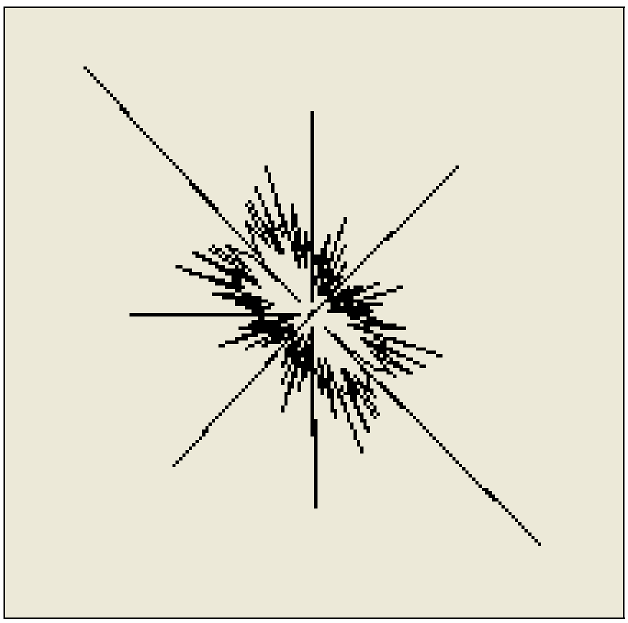

Figure 14. Polar Histogram of Melt Blown Nonwoven Containing 65% Cotton

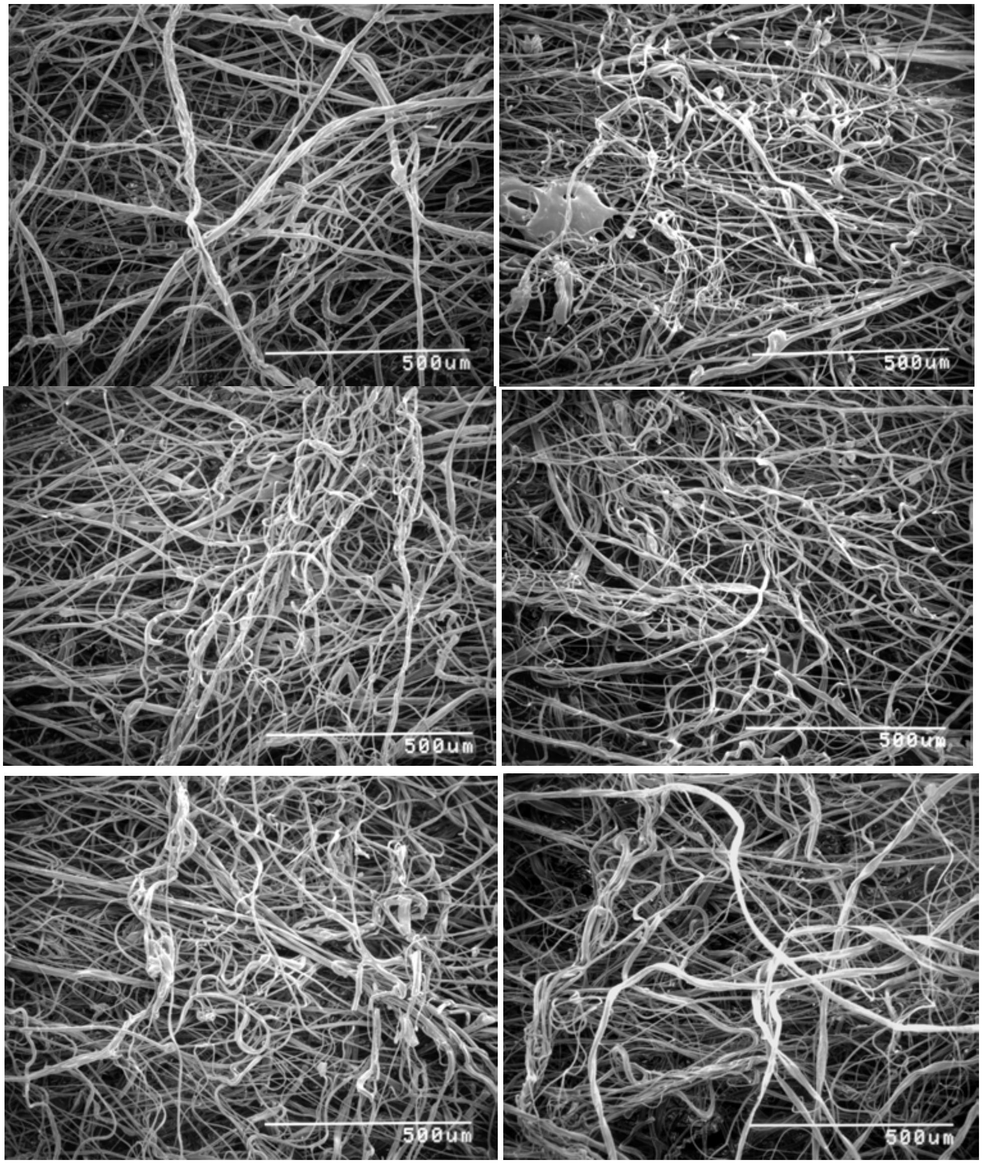

Figure 15. Opposite Sides of Three Fabric Areas.

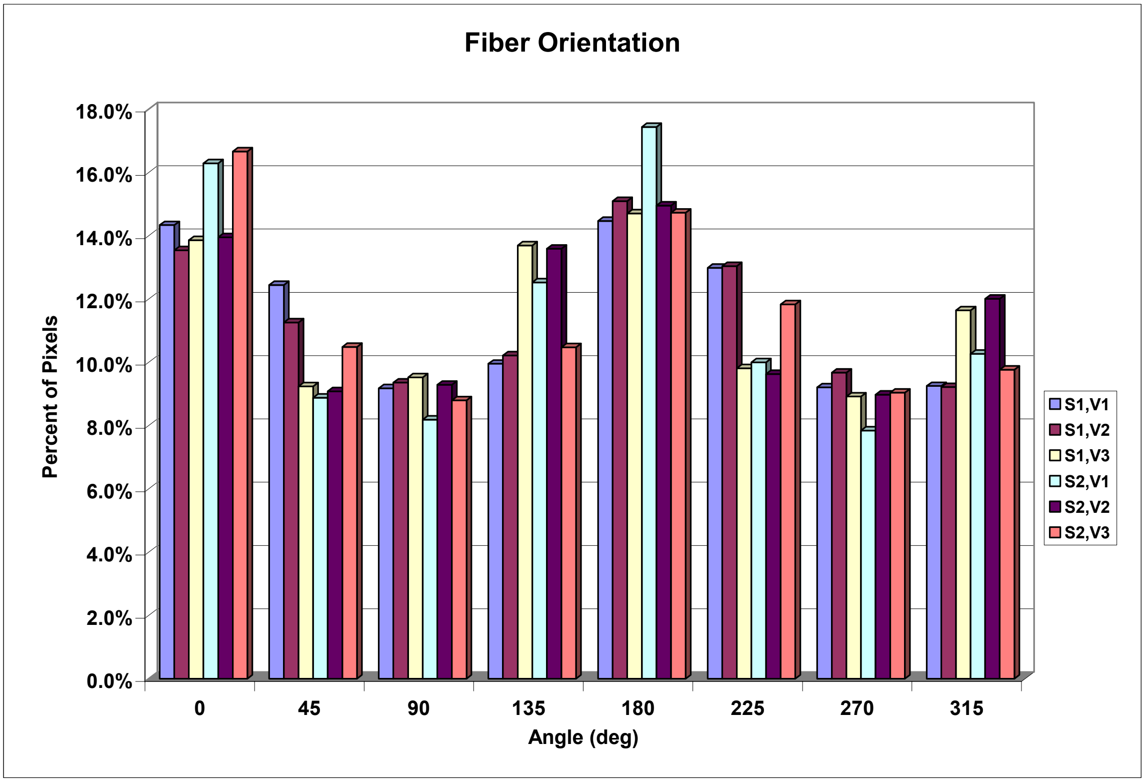

Figure 16. Bar Graph Showing Cumulative Orientation Values for Opposite Sides of Three Fabric Areas.