

Uniformity measurement of wet laid nonwovens using an image analyzer

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ABSTRACT: *An image analyzer evaluated the uniformity or quality of wet laid nonwovens with a wide range of physical properties. This paper presents a new method to assess material quality and a material ranking based on a formation or quality uniformity index.*

KEYWORDS: *Evaluation, homogeneity, image analysis, measurement, nonwovens, physical properties, quality, test methods, wet lay process.*

The availability of affordable high-speed computers, charge-coupled device (CCD) cameras, and imaging software has enabled the study of sheet and other parameters not possible only a short time ago. With such equipment, it quickly becomes apparent that the performable tasks are almost limitless. These may include identifying objects; measuring areas, diameters, contamination, and product quality; and other applications too extensive to discuss in detail.

This paper presents an investigation to evaluate the quality of a range of nonwoven products. The study involved a series of wet laid nonwovens having a range of basis weights, colors, fiber types, and visual uniformity or quality. The researcher hoped the work would lead to the development of methods that would give a relative rating of product quality.

Material evaluation

The quality image analysis study comprised the range of products noted in Table I. The specimen identification indicates the particular fiber type shown in the table. All the nonwoven products are wet laid and exhibit a range of physical properties. Basis weights range from 27.5 g/m² to 200 g/m². Fiber types include polyester with wood pulp, carbon, glass, and rayon. The colors of the samples range from white to black. The glass nonwoven binder exhibits varying degrees of yellowing across the specimen. Because of the range of nonwoven parameters, a procedure which evaluated quality for such a heterogeneous mix of samples would probably apply to most nonwovens and paper.

Quality assessment

To establish some degree of reliability for a visibly perceived ranking of quality, the author ranked the specimens

for uniformity as shown in Table I. A rank of 1 indicates best uniformity and 8 indicates least uniformity. The ranking was somewhat difficult due to the wide range of basis weights, fiber types, colors, flocculation, and content of sticks or logs.

Some researchers have used a histogram to evaluate quality.¹ A luminance histogram is useful when the basis weights and colors of the specimens are approximately the same. One must know how to interpret the shape of the histogram, however. In addition, the shape of the histogram can vary depending on the f-stop and the region of interest. Figure 1 illustrates the effect on the shape of the histogram when the f-stop of the CCD camera varies. With f-22, the histogram truncates on the left edge and negates a correct result for luminance. With f-5.6, the histogram skews to the right and is too narrow to obtain meaningful results. The proper setting is f-8 for this specimen, because it gives an evenly shaped bell histogram. The latter setting will give good results when measuring luminance. The luminance histogram can be useful for determining differences of specimens having the same basis weight or light transmittance. It is not satisfactory with transmitted light for specimens which range in basis weight. Because of this, another approach was necessary to assess nonwoven quality.

Rather than develop new macros or mathematical models for ranking different basis weight specimens, this approach used the most simple technique possible with the image analysis

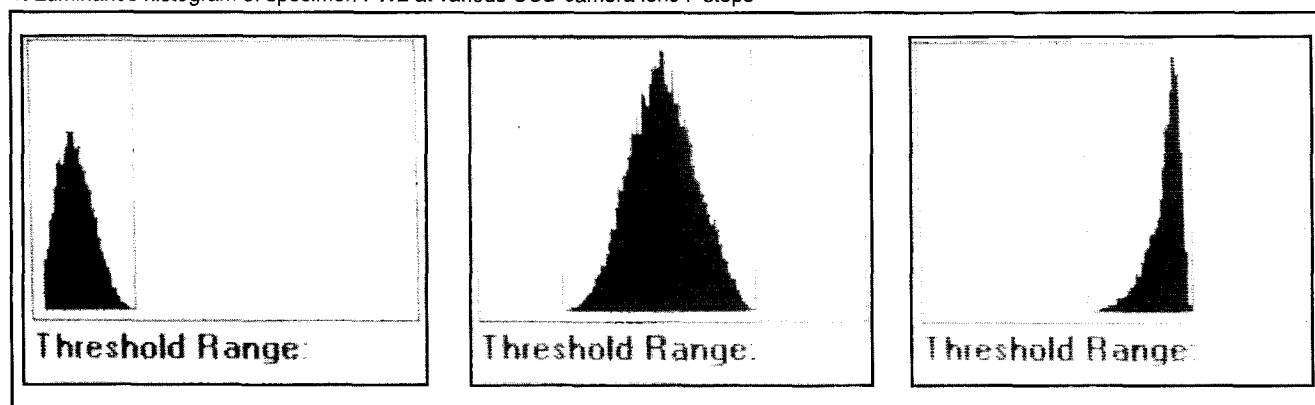
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¹Smith, J. H., Tappi J. 75(5): 121(1992).

I. Wet laid nonwoven specifications

<i>Specimen</i>	<i>Process</i>	<i>Fiber type</i>	<i>Color</i>	<i>Basis weight, g/m²</i>	<i>Visual uniformity rating</i>
PW1	Wet laid	Polyester and wood pulp	White	27.5	1
PW2	Wet laid	Polyester and wood pulp	White	47.5	7
PW3	Wet laid	Polyester and wood pulp	White	92.5	6
C1	Wet laid	Carbon	Black	55	4
C2	Wet laid	Carbon	Black	65	5
C3	Wet laid	Carbon	Black	77.5	3
G1	Wet laid	Glass	Yellowed white	155	2
R1	Wet laid	Rayon	White	200	8

1. Luminance histogram of specimen PW2 at various CCD camera lens f-stops



software which was available. The measurement tools were multiple light and dark points, lines, and areas. When using transmitted light, the light points, lines, and areas are equivalent to thin places in the sheet. Conversely dark points, lines, and areas correspond to fibers, flocks, sticks, and logs.

The first requirement for the study was the most uniformly possible light box. Photographic light boxes ordinarily find use to examine negatives and slides, do tracings, etc. The initial work indicated that the best commercially available light box for transmitted light was inadequate. Assessment of light points, lines, and area objects showed that they were consistently in the center of the specimen and oriented in the direction of the fluorescent light tube. The dark points, lines,

and area object settings were consistently at the edge of the specimens. This occurred even with use of a thick white opaque plastic sheet to diffuse the light. An attempt to correct for the apparently uneven lighting using available software tools or macros was not completely satisfactory.

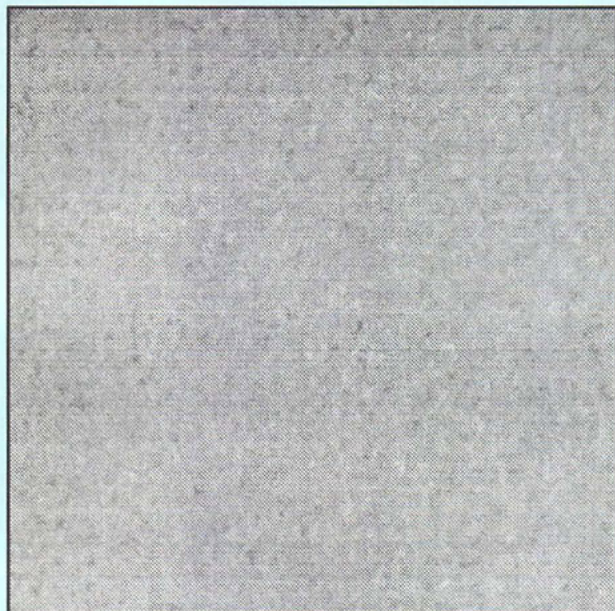
To overcome the difficulty with uneven lighting, the researchers constructed a light box using 1.27-cm plywood with outside dimensions of 53 x 53 x 21 cm containing eight 15-watt 46.7-cm long fluorescent tubes. The interior of the box used discarded white glass beaded photographic screen material to diffuse the light. A 7.62-cm diameter, 32-ft³/min, 38-dB cooling fan exhausted the heat generated by the fluorescent lights. The fan was outside the light box to minimize light disruption

inside the box. A nonwoven filter and protective screen were on the light box on the side opposite of the fan. Two layers of white opaque plastic skylight sheets at or near the top of the light box separated by 5 cm assisted in the uniform diffusion of light. The total cost for materials for the light box was US\$ 278.

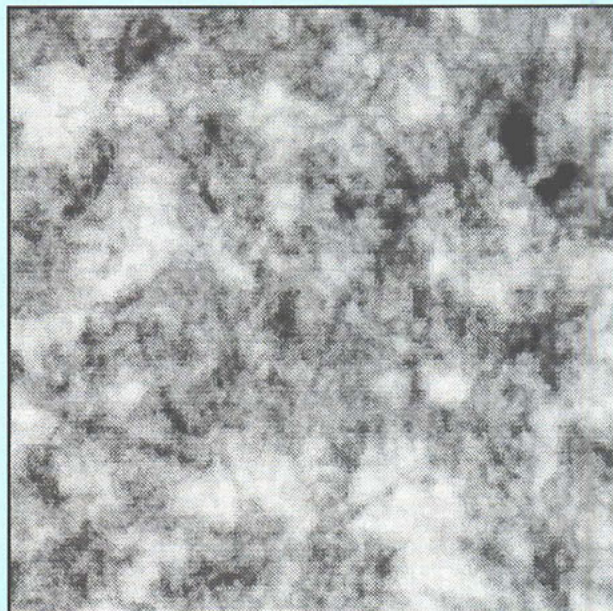
Although the overall dimensions of the opaque plastic sheets were 53 x 53 cm, the uniform light area in the center of the light box was only slightly different than 50 cm², i.e., only 7.07 x 7.07 cm. While this area was substantially smaller than desired, the 50-cm² region of interest for both light and dark points, lines, and areas provided excellent results for light uniformity during testing.

Because the various specimens had

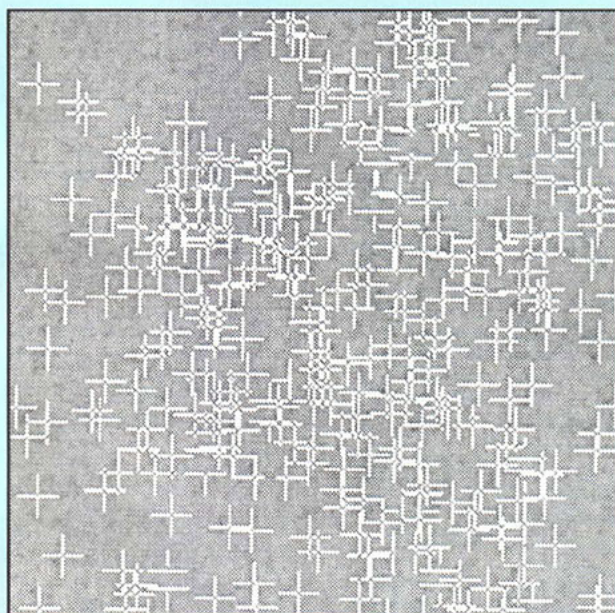
2. Video monitor image of specimens PW1 and R1 illustrating both light and dark object points, lines, and areas



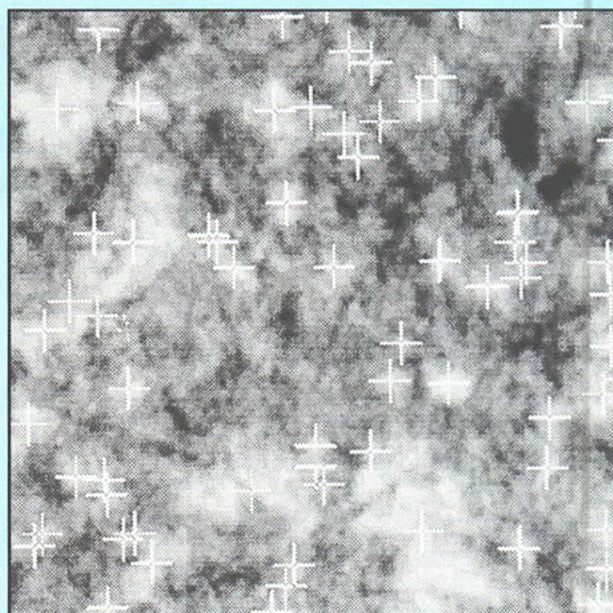
PW1 image only



R1 image only

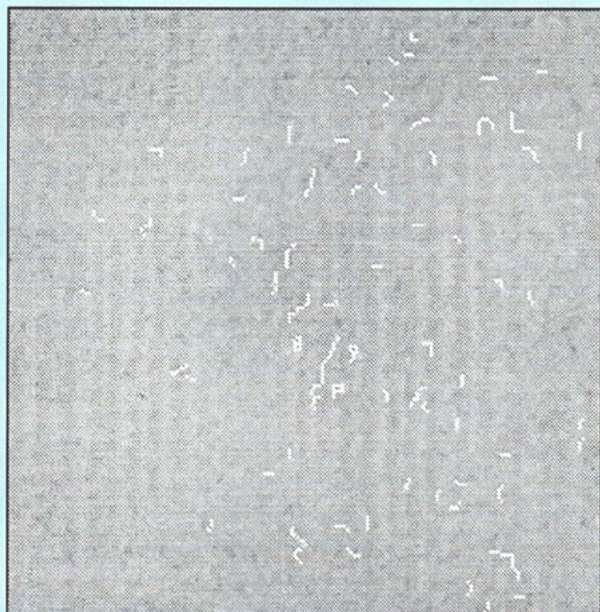


PW1 light object points

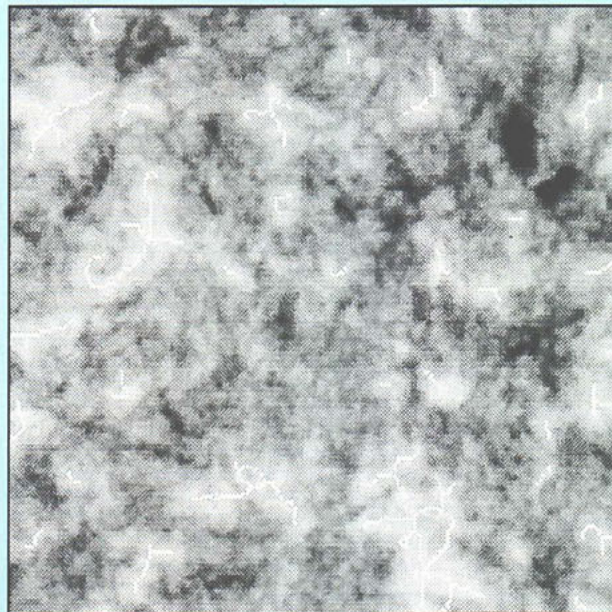


R1 light object points

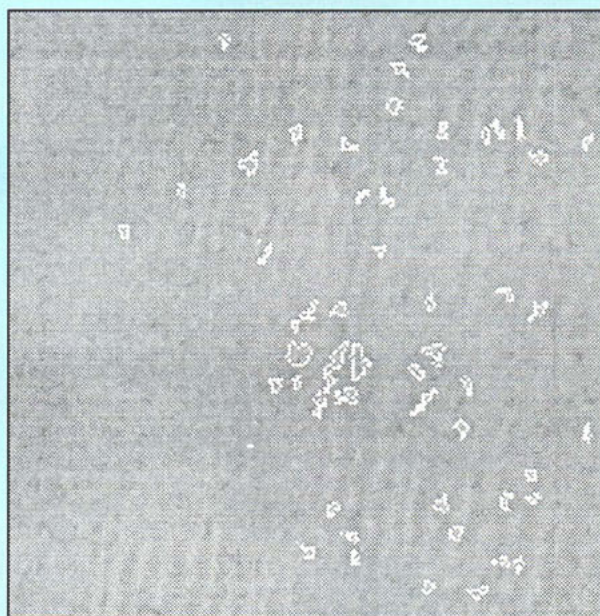
2. Video monitor image of specimens PW1 and R1 illustrating both light and dark object points, lines, and areas



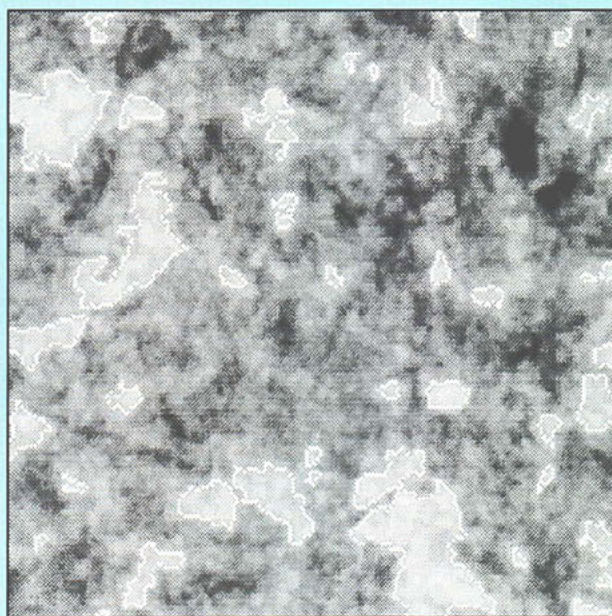
PW1 light object lines



R1 light object lines

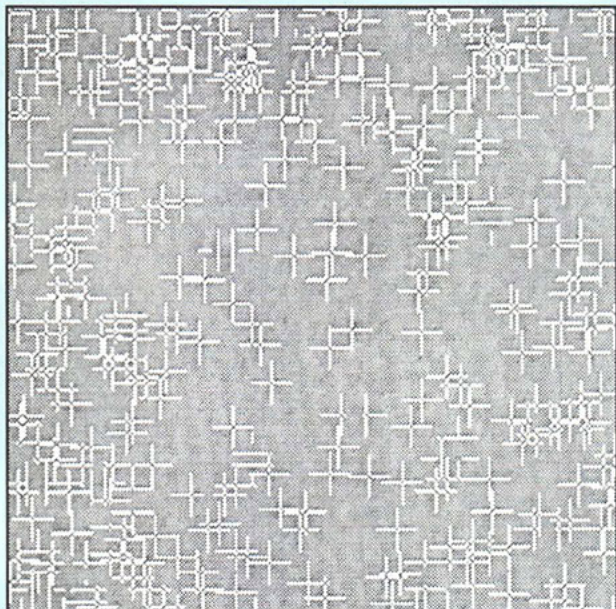


PW1 light object areas

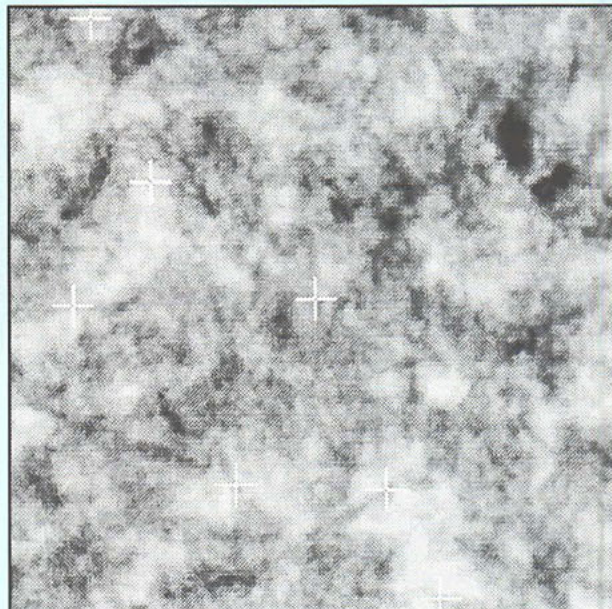


R1 light object areas

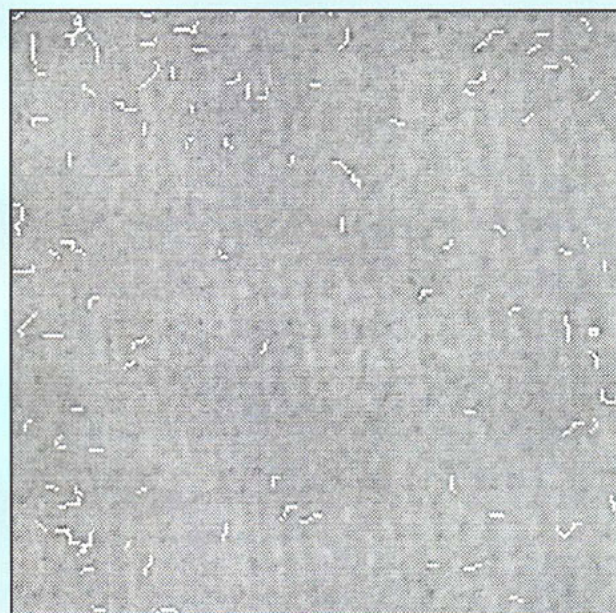
2. Video monitor image of specimens PW1 and R1 illustrating both light and dark object points, lines, and areas



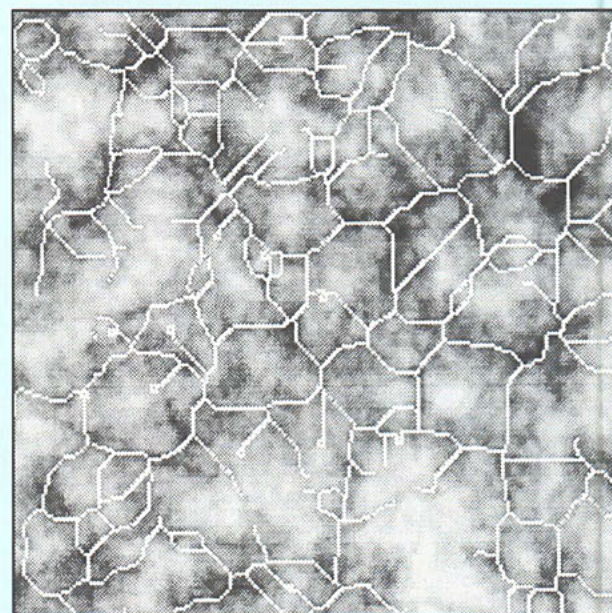
PW1 dark object points



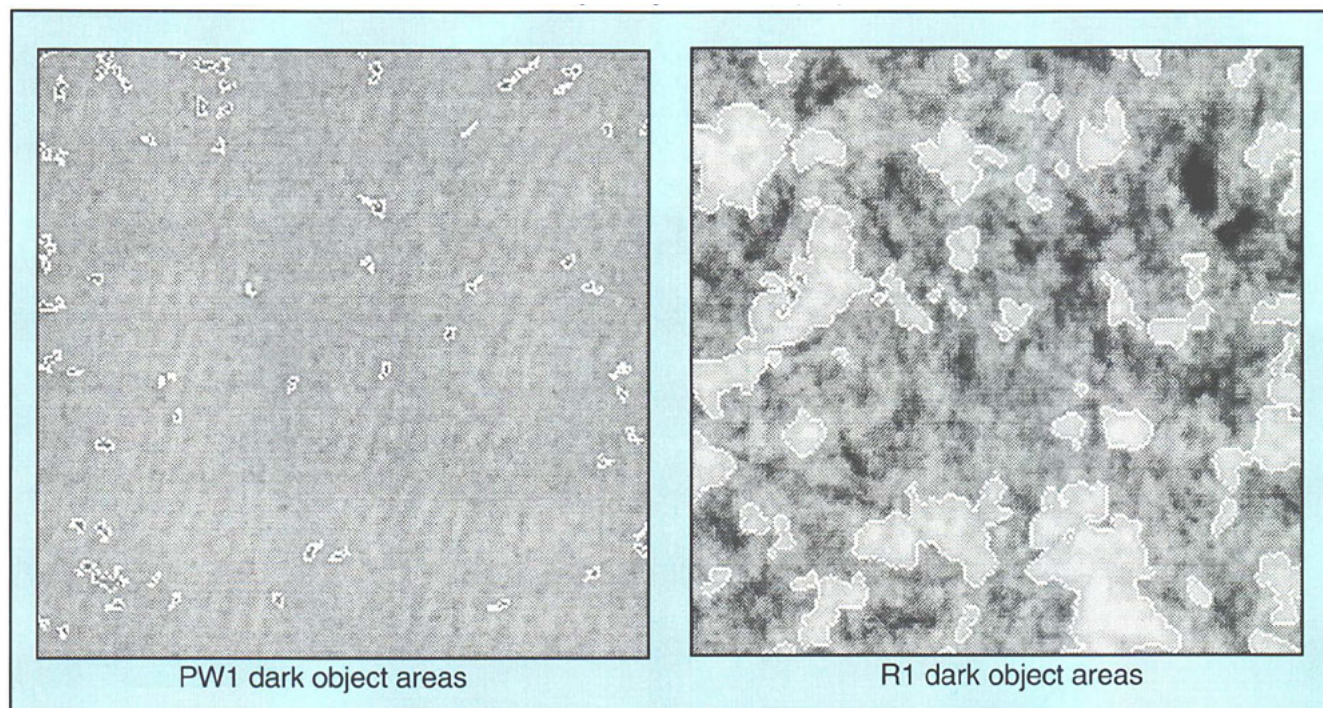
R1 dark object points



PW1 dark object lines



R1 dark object lines



basis weights of 27.5–200 g/m², the same CCD camera f-stop did not provide the proper histogram lighting value for all specimens. The f-stop necessary to obtain a properly positioned and shaped histogram varied between f-4 for the heavy weight specimen to f-16 for the light weight specimen. Variation of the f-stop provided a histogram similar to that shown in the center of Fig. 1.

For each of the eight different specimens there were five machine direction (MD) and five cross machine direction (CMD) test replications. All replicate tests for a given specimen used one 20 x 20 cm sample. The region of interest for each test was 7.07 x 7.07 cm or 50 cm². The data included light and dark points, lines, and areas. Specimens PW1 and R1 of Fig. 2 illustrate the differences in the visually best and worst samples as well as the type of material collected.

Testing used the default threshold values for light objects and dark objects. Table II lists the individual means, standard deviations, and percent coefficients. The individual means standard deviation according to %CV was unsatisfactory so another ap-

proach was necessary.

Table III summarizes the results for all the specimens and includes means and root mean square values. The determination of the overall mean points used the averages of the mean light points and mean dark parts. The light and dark lines and the light and dark areas used the same technique. The investigator also determined the root mean square of light and dark points. In a similar manner, he determined the root mean square of light and dark lines and then the root mean square of light and dark areas.

It was apparent that more points, lines, and areas produced a better perception of quality of the specimen. One only needs to compare the most uniform specimen, PW1, with the worst specimen, R1, in Table II. As a result, the researcher decided to develop a rating index to compare the various methods by assigning the PW1 specimen values in Table III a base value of 10. He calculated proportional index values for the other specimens. Table III lists the resultant index values for light and dark points, lines, and areas. He obtained the overall mean points, lines, and areas by combining both

light and dark values and establishing the average for a given characteristic. He established the overall root mean points, lines, and areas by first squaring each value and then taking the square root of the mean.

Because the index for light and dark points, lines, and areas all seemed to give the same trend, Table IV presents a common mean index and a common root mean square (RMS) index. Using the various index values obtained, Table V lists the ranking order obtained this way as well as the visual ranking. It is apparent from Table V that most of the index methods tended to rank the samples in the same order. Table VI illustrates this further. All index methods listed the ranking order of the PW1, C3, PW3, and R1 specimens exactly the same way as each had the same ranking eight times. Samples C1, C2, PW2, and G1 also had a high frequency ranking of 5–7 times out of 8 possible methods. The samples listed in order by frequency ranking order exhibit no overlapping or ties of sample numbers.

Using the ranking order from Table VI, the investigator compared the

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II. Luminance multiple light and dark points, lines and areas

Sample	PW1 Light	PW1 Dark	PW2 Light	PW2 Dark	PW3 Light	PW3 Dark	C1 Light	C1 Dark	C2 Light	C2 Dark	C3 Light	C3 Dark	G1 Light	G1 Dark	R1 Light	R1 Dark
Points																
1MD	360	323	240	163	198	102	366	252	409	201	429	256	222	166	71	68
2MD	469	449	211	159	185	140	382	238	400	193	451	214	230	156	65	91
3MD	482	427	223	210	199	110	408	216	414	182	410	211	263	168	76	49
4MD	467	397	213	154	218	129	378	225	406	243	456	224	243	162	74	76
5MD	380	454	216	181	217	119	364	247	389	222	414	214	199	186	71	81
6CMD	522	396	230	188	205	121	389	237	398	200	410	266	261	167	56	86
7CMD	424	426	216	150	212	149	394	221	372	235	415	214	275	176	57	67
8CMD	451	376	248	182	199	121	369	225	413	191	390	186	221	172	82	78
9CMD	428	427	227	163	207	136	393	292	420	290	397	268	220	167	60	66
10CMD	491	387	228	180	200	126	375	195	418	183	364	234	254	206	63	58
Mean	447.4	406.2	225.2	173	204	125.3	381.8	234.8	403.9	214	413.2	228.7	238.8	172.6	67.5	72
Std. Dev.	50.15	39.11	12.01	18.48	10.01	13.98	14.16	25.93	14.77	34.06	27.17	26.91	24.16	14.23	8.66	12.88
%CV	11.21	9.63	5.33	10.68	4.91	11.16	3.71	11.04	3.66	15.92	6.58	11.77	10.12	8.24	12.83	17.88
Lines																
1MD	108	103	116	91	105	73	132	120	144	76	145	113	90	110	60	61
2MD	183	172	114	104	102	86	116	138	146	85	164	122	96	77	77	63
3MD	177	150	106	98	111	70	125	107	165	95	131	101	132	98	63	68
4MD	198	144	102	98	103	84	131	145	134	126	193	124	94	77	57	69
5MD	127	160	116	112	101	76	130	122	144	94	130	92	87	97	65	51
6CMD	215	137	120	118	131	81	129	118	131	88	161	142	111	112	47	79
7CMD	145	165	101	89	106	93	129	129	130	118	159	140	137	96	61	58
8CMD	204	145	104	116	86	77	125	162	152	93	155	107	111	109	59	50
9CMD	178	158	109	107	102	98	151	168	139	116	158	149	90	92	51	62
10CMD	196	134	114	102	108	80	120	117	138	82	150	141	111	141	51	44
Mean	173.1	146.8	110.2	103.5	105.5	81.8	128.8	132.6	142.3	97.3	154.6	123.1	105.9	100.9	59.1	60.5
Std. Dev.	35.19	19.62	6.68	9.89	11.15	8.74	9.31	20.27	10.57	16.87	17.98	19.59	17.73	18.71	8.54	10.32
%CV	20.33	13.37	6.06	9.56	10.57	10.69	7.23	15.28	7.43	17.34	11.63	15.91	16.74	18.54	14.46	17.06
Areas																
1MD	66	66	97	89	76	49	103	82	118	51	113	72	66	71	45	42
2MD	138	112	96	71	84	50	87	92	117	58	120	70	74	62	46	57
3MD	130	106	94	83	87	47	100	68	132	59	112	67	88	68	49	49
4MD	156	105	81	70	91	56	101	99	120	65	126	85	72	53	44	51
5MD	78	111	98	75	85	41	103	76	107	60	98	68	61	65	45	46
6CMD	148	89	101	85	103	52	101	82	113	45	113	84	87	70	35	61
7CMD	108	109	85	67	93	62	99	73	100	84	107	68	110	74	38	40
8CMD	144	84	95	83	79	64	87	85	108	57	103	71	81	78	45	41
9CMD	120	102	92	82	85	64	92	97	121	74	104	87	72	70	39	39
10CMD	146	85	101	78	79	58	93	69	111	51	105	91	84	79	39	39
Mean	123.4	96.9	94	78.3	86.2	54.3	96.6	82.3	114.7	60.4	110.1	76.3	79.5	69	42.5	46.5
Std. Dev.	30.67	15.18	6.51	7.29	7.94	7.79	6.29	11.08	8.94	11.53	8.44	9.29	13.94	7.70	4.43	7.84
%CV	24.85	15.66	6.93	9.31	9.21	14.35	6.51	13.46	7.80	19.09	7.66	12.17	17.53	11.16	10.42	16.85

III. Mean multiple light and dark points, lines, and areas

Specimen	Mean light	Mean dark	Overall mean	Overall root mean square	Light index	Dark index	Overall mean index	Overall root mean square index
Points								
PW1	447.40	406.20	426.80	427.30	10.00	10.00	10.00	10.00
PW2	225.20	173.00	199.10	200.80	5.03	4.26	4.66	4.70
PW3	204.00	125.30	164.65	169.29	4.56	3.08	3.86	3.96
C1	381.80	234.80	308.30	316.94	8.53	5.78	7.22	7.42
C2	403.90	214.00	308.95	323.21	9.03	5.27	7.24	7.56
C3	413.20	228.70	320.95	333.94	9.24	5.63	7.52	7.82
G1	238.80	172.60	205.70	208.35	5.34	4.25	4.82	4.88
R1	67.50	72.00	69.75	69.79	1.51	1.77	1.63	1.63
Lines								
PW1	173.10	146.80	159.95	160.49	10.00	10.00	10.00	10.00
PW2	110.20	103.50	106.85	106.90	6.37	7.05	6.68	6.66
PW3	105.50	81.80	93.65	94.40	6.09	5.57	5.85	5.88
C1	128.80	132.60	130.70	130.71	7.44	9.03	8.17	8.14
C2	142.30	97.30	119.80	121.89	8.22	6.63	7.49	7.60
C3	154.60	123.10	138.85	139.74	8.93	8.39	8.68	8.71
G1	105.90	100.90	103.40	103.43	6.12	6.87	6.46	6.44
R1	59.10	60.50	59.80	59.80	3.41	4.12	3.74	3.73
Areas								
PW1	123.40	96.90	110.15	110.94	10.00	10.00	10.00	10.00
PW2	94.00	78.30	86.15	86.51	7.62	8.08	7.82	7.80
PW3	86.20	54.30	70.25	72.04	6.99	5.60	6.38	6.49
C1	96.60	82.30	89.45	89.74	7.83	8.49	8.12	8.09
C2	114.70	60.40	87.55	91.66	9.29	6.23	7.95	8.26
C3	110.10	76.30	93.20	94.72	8.92	7.87	8.46	8.54
G1	79.50	69.00	74.25	74.44	6.44	7.12	6.74	6.71
R1	42.50	46.50	44.50	44.54	3.44	4.80	4.04	4.02

IV. Common average and root mean square index

Specimen	Overall mean points index	Overall mean lines index	Overall mean areas index	Common mean index	Overall root mean points index	Overall root mean lines index	Overall root mean areas index	Common RMS index
PW1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
PW2	4.66	6.68	7.82	6.39	4.70	6.66	7.80	6.51
PW3	3.86	5.85	6.38	5.36	3.96	5.88	6.49	5.55
C1	7.22	8.17	8.12	7.84	7.42	8.14	8.09	7.89
C2	7.24	7.49	7.95	7.56	7.56	7.60	8.26	7.81
C3	7.52	8.68	8.46	8.22	7.82	8.71	8.54	8.37
G1	4.82	6.46	6.74	6.01	4.88	6.44	6.71	6.06
R1	1.63	3.74	4.04	3.14	1.63	3.73	4.02	3.30

ranking with the initial visual ranking. With the exception of the G1 specimen having a difference of 4 between visual and final order, the ranking order agreed well with the visual order. Possible reasons that the G1 specimen ranked higher visually than by the test index methods are that glass fibers are transparent, the specimen exhibited uneven yellowing across the sample, and there may have been a poor visual ranking. This does not indicate that the test method is not useful for glass. Rather it ranks glass fabrics as a group. It does not provide a comparison, however, with other fiber types. The exact reason for the discrepancy is unknown.

Table VII lists the absolute difference between the various methods using the ranking order determined by frequency of index methods. The mean lines index, mean areas index, common mean index, mean lines index, and common RMS index all had zeros indicating no difference existed. The root mean areas index, overall mean points index, and root mean points index each had a total sum difference of only 2, 4, and 4 respectively. With none of the individual differences ever exceeding 1, it is possible to conclude that all methods ranked the nonwovens in a relatively similar way. Since both the common mean index and the common RMS index ranked all specimens in the same order, however, it is possible to use either of these.

Discussion

The author has developed a method using an image analyzer that will rank nonwovens for perceived quality. Using transmitted light, the characteristics of light and dark, points, lines, and areas will establish a ranking index. Greater numbers of light and dark points, lines, and areas which are detected provide a better perception of nonwoven quality. This is a "salt and pepper" effect. If one takes equal parts of salt and pepper and mixes them thoroughly, the mixture would appear uniformly gray at only a very short distance. On the other hand, if one

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V. Specimen visual and index ranking order

Specimen	Visual ranking order	Overall mean points index order	Overall mean lines index order	Overall mean areas index order	Common mean index order	Overall root mean points index order	Overall root mean lines index order	Overall root mean areas index order	Common RMS index order
PW1	1	1	1	1	1	1	1	1	1
PW2	7	6	5	5	5	6	5	5	5
PW3	6	7	7	7	7	7	7	7	7
C1	4	4	3	3	3	4	3	4	3
C2	5	3	4	4	4	3	4	3	4
C3	3	2	2	2	2	2	2	2	2
G1	2	5	6	6	6	5	6	6	6
R1	8	8	8	8	8	8	8	8	8

VII. Root squared difference between most frequent ranking order and individual index order

Specimen	Most frequent ranking order	Overall mean points index diff.	Overall mean lines index diff.	Overall mean areas index diff.	Common mean index diff.	Overall root mean points index diff.	Overall root mean lines index diff.	Overall root mean areas index diff.	Common RMS index diff.
PW1	1 (Best uniformity)	0	0	0	0	0	0	0	0
C3	2	0	0	0	0	0	0	0	0
C1	3	1	0	0	0	1	0	1	0
C2	4	1	0	0	0	1	0	1	0
PW2	5	1	0	0	0	1	0	0	0
G1	6	1	0	0	0	1	0	0	0
PW3	7	0	0	0	0	0	0	0	0
R1	8 (Least uniformity)	0	0	0	0	0	0	0	0
Sum		4	0	0	0	4	0	2	0

were to mix white pine wood chips with black oak wood chips, the uniform mixture would appear speckled or blotchy at the same viewing distance. Thus more points, lines, or areas detected by the image analyzer provide better quality perception. The more uniform nonwoven is the one having numerous fibers distributed in a very uniform way. The nonuniform nonwoven would be the one having flocculation or poor fiber distribution. **□**

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VI. Most frequent ranking order obtained

Specimen	Most frequent ranking order number	Difference between visual and final order
PW1	No. 1 for 8 times	0
C3	No. 2 for 8 times	1
C1	No. 3 for 5 times	1
C2	No. 4 for 5 times	1
PW2	No. 5 for 6 times	2
G1	No. 6 for 6 times	4
PW3	No. 7 for 8 times	1
R1	No. 8 for 8 times	0
	Difference between visual and this ranking	10