Mechanism of Tensile Failure of Cohesively Bonded Blended Nonwoven Fabrics

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MECHANISM OF TENSILE FAILURE OF

COHESIVELY BONDED BLENDED NONWOVEN FABRICS

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SUMMARY

In this thesis, the tensile behavior of partially cohesively bonded nonwoven fabrics made of viscose rayon/ polyester fiber blends is investigated. The partial bonding is affected between the rayon fibers by a treatment in an aqueous zinc chloride solution.

Based on tenacity, elongation, modulus and fiber utilization efficiency data of webs made of 6 different rayon/polyester fiber blends, it is concluded that the mechanism of tensile rupture of the investigated bonded webs incorporates two types of failure, namely; cohesive failure and interfiber slippage, the proportion of each depends on the percentage of bondable fibers in the blend.

CHAPTER I

INTRODUCTION

Recently, a method has been developed for making cohesively bonded nonwoven fabrics without using high temperature bonding or adhesive binders. In this method, a carded web containing cellulosic fibers is treated with aqueous zinc chloride. Cohesive bonds are formed at cellulose-cellulose contact points which strengthen the web.

The objective of this thesis is to prepare and evaluate the properties of cohesively bonded cellulosic fiber-(rayon or cotton)-webs incorporating other thermoplastic fibers such as polyester. Some of the main characteristics of such nonwoven web are: (a) absence of adhesives (b) high flexibility, since the bonds are discrete especially at points of crossover of dissimilar fibers, and (c) good moisture absorption.

The X-ray diffraction measurements carried out by Patil et al. (1) on cotton fibers have shown that concentrated aqueous solution of zinc chloride ($ZnCl_2$) causes decrystallization of cellulosic fibers. The degree of decrystallization depends strongly upon Zinc Chloride concentration and the time and temperature of treatment.

Such decrystallization occurs only in a narrow zinc chloride concentration range (60-75% by weight) and essentially amorphous fibers can be produced under certain treatment conditions (Figure I-1). After the zinc chloride is washed out, recrystallization occurs, and adjacent fibers can cocrystallize and form cohesive bonds.

In a recent publication, the Textile Research Institute reported on a study of cellulose-based nonwoven fabrics in which zinc chloride aqueous solution is used to effect bonding between rayon fibers. In this study, the effect of zinc chloride aqueous solution concentration on the tensile strength of an all-rayon nonwoven and a 75% rayon / 25% polyester blend was investigated (Figure I-2). A concentration of zinc chloride of about 56% by weight has been recommended for obtaining maximum fabric tensile strength.

In this thesis, blends of rayon and polyethylene terephthalate fibers were formed into carded webs. The fiber mats were saturated in 56% concentration aqueous solution of zinc chloride for bonding the cellulosic fibers. After washing and drying, the fabric tensile properties were evaluated.

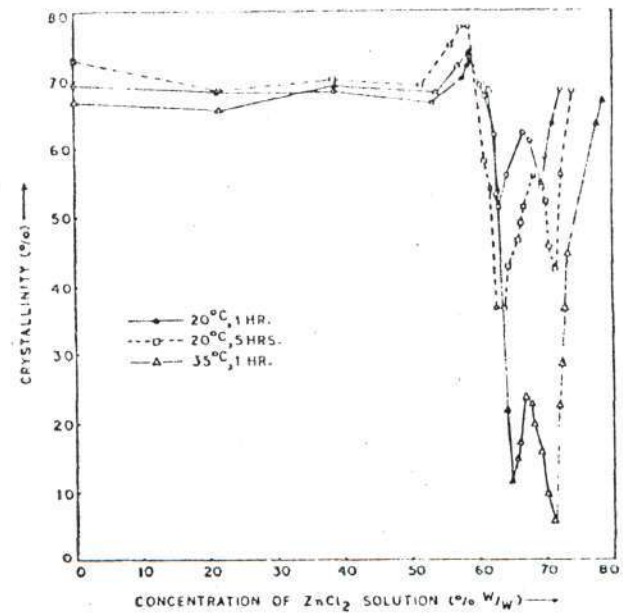

Figure I-1. Decrystallization of Cotton by Zinc Chloride (Patil et al (1))

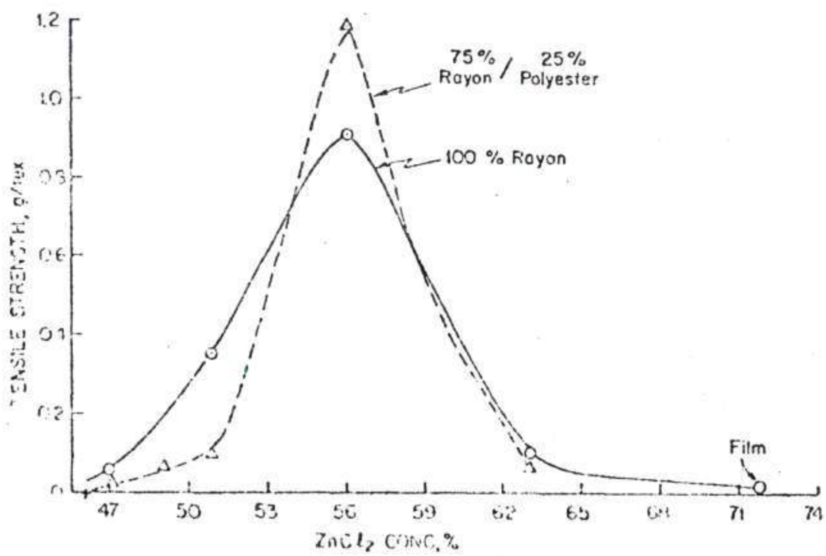

Figure I-2. Tensile Strength of Zinc Chloride Bonded Nonwovens as a Function of Zinc Chloride Concentration(2)

CHAPTER II

MATERIAL USED IN EXPERIMENTAL WORK AND TECHNIQUES OF PREPARATION OF FIBER WEBS

In order to study the effect of blend ratio on fabric strength, six different blends of rayon and polyester were formed into carded webs, Table II-1. The properties of single rayon and polyester fibers used have been evaluated, see Figure II-1 and Table II-2.

The rayon fibers were provided by Courtaulds North America, Inc., and the polyester fibers by E. I. Du Pont De Nemours & Co., Inc.

Fiber mats were prepared by blending polyester fibers with rayon fibers according to the specific blend ratio. The fibers were thoroughly blended before being fed into a miniature card for web formation. The obtained carded web was then passed through the needle punching machine in order to achieve some bonding, so that it can be handled without failure.

The punched webs were saturated with concentrated zinc chloride solution (56% by weight). The excess solution was squeezed out through the use of a screen. Bonding was then achieved through the application of pressure (19 psi) for 1 min. at 100°C in a PHI molding press using teflon sheets above and below the saturated fiber mat. Immediately after bonding, the fiber mats were washed in running water in order to remove zinc chloride solution. Later the mats were pressed between two screens in order to remove excess water and dried in PHI molding press at 100°C and under a pressure of 20 psi for one hour.

Table II-1. Rayon-Polyester Fiber Blend Ratios

	(%) by Weight	
Blend No.	Rayon Fiber	Polyester Fiber
1	100	0
2	75	25
3	60	40
4	50	50
5	40	60
6	25	75

Table II-2. Fiber Properties

Property / Fiber	Denier	Length (in)	Elongation (%)	Tenacity (gpd)	Modulus (gpd)
Rayon	1½	1 9/16	19.12	2.45	38.26
Polyester	1½	1½	61.49	5.01	33.97

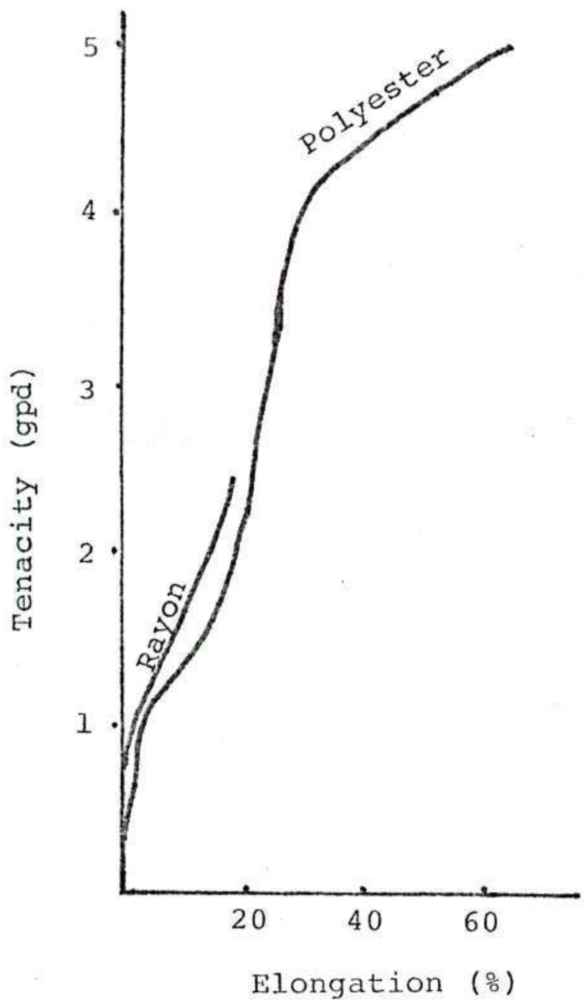

Figure II-1. Typical Load-Elongation Behavior of Single Rayon and Polyester Fibers.

CHAPTER III

MEASUREMENTS OF PROPERTIES OF BONDED FIBER WEBS

The tensile strength, modulus and breaking elongation of the bonded nonwoven webs have been measured in order to assess the effectiveness of bonding achieved in the various blends. In addition to that, the fiber utilization efficiency(*) has been computed for the various nonwoven webs and the individual fibers were examined before and after bonding using the Mini-Sem Scanning Electron Microscope.

The measurements of tensile grab tenacity, breaking elongation and secant modulus at breaking point and the computed values of fiber utilization efficiency for the various blends before and after zinc chloride treatment are shown in Tables III-1 and III-2 respectively and in Figures III-1 to III-8. The secant modulus at breaking point has been used

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(*) The fiber utilization efficiency is defined as the ratio of fabric tenacity (in gms/denier) to average (by weight) fiber tenacity in the blended web. The fabric tenacity is obtained by first dividing the grab tensile breaking strength measurements by the fabric basis weight (oz./sq.yd.) and the test specimen width, thus normalizing the fabric strength into units of (lb/in/oz/sq.yd). The normalized fabric strength data is then divided by 17 to obtain the tenacity expressed in units of gms/denier.

instead of the initial modulus in order to avoid any errors in drawing the initial tangent line to the load-elongation curve which exhibited a pronounced stick-slip behavior especially at the early part of deformation. The percentage change in web tenacity due to zinc chloride treatment is shown in Figure III-9.

The surface of rayon fibers has been examined under the scanning electron microscope before and after zinc chloride treatment. Figure III-10 shows a scanning electron photomicrograph of rayon fibers before treatment. Figure III-11 shows the same fibers after treatment with 56% concentration zinc chloride solution.

Table III-1. Grab Test Tenacity, Elongation, Secant Modulus at Breaking Point and Fiber Utilization Efficiency of Nonwoven Webs After Needle Punching (170 Needle Punches/ In^2) and Before Zinc Chloride Treatment

Blend No.	Fabric Tenacity (gpd)	Elongation (%)	Fabric Secant Modulus (gpd/ Unit of Strain) $x10^{-4}$	Average (by wt.) Fiber Tenacity	Fiber Utilization Efficiency (%)
(1) 100% rayon	0.1875	81	23.15	2.45	7.65
(2) 75% rayon x 25% polyester	0.1410	102	13.82	3.09	4.56
(4) 50% rayon x 50% polyester	0.1250	100	12.50	3.73	3.35
(6) 25% rayon x 75% polyester	0.1325	135	9.81	4.37	3.03

Table III-2. Grab Test Tenacity, Elongation, Secant Modulus at Breaking Point and Fiber Utilization Efficiency of Nonwoven Webs After Zinc Chloride Treatment

Blend No.	Fabric Tenacity (gpd)	Elongation (%)	Fabric Secant Modulus (gpd/ Unit of Strain) $\times 10^{-4}$	Average (by wt.) Fiber Tenacity	Fiber Utilization Efficiency (%)
(1) 100% rayon	0.2257	54.4	41.49	2.45	9.21
(2) 75%rayon x25%polyester	0.2233	59.7	37.4	3.09	7.23
(3) 60%rayon x40%polyester	0.2830	38.0	74.47	3.47	8.16
(4) 50%rayon x50%polyester	0.3270	57.3	57.07	3.73	8.77
(5) 40%rayon x60%polyester	0.2340	84.1	27.82	3.98	5.88
(6) 25%rayon x75%polyester	0.1489	109	13.66	4.37	3.41

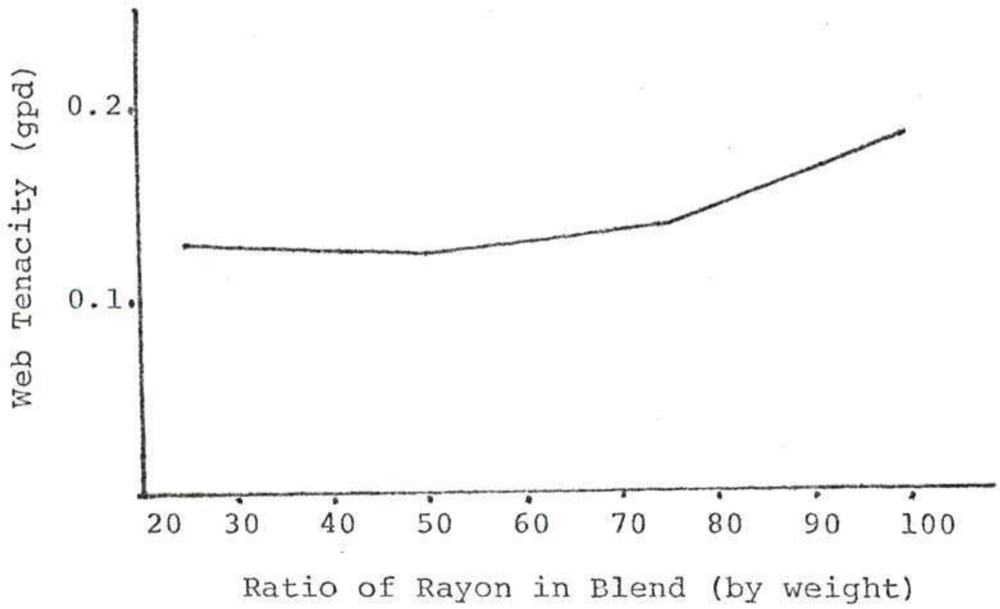

Figure III-1. Tenacity of Rayon/Polyester Webs After Needle Punching (170 Needle Punches/In^2) and Before Zinc Chloride Treatment

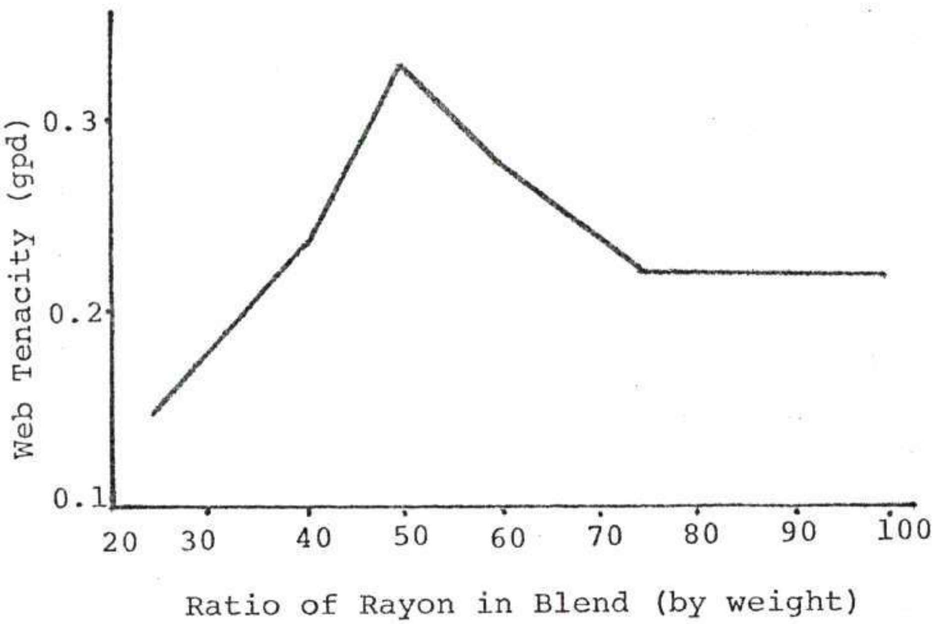

Figure III-2. Tenacity of Rayon/Polyester Nonwoven Webs After Zinc Chloride Treatment

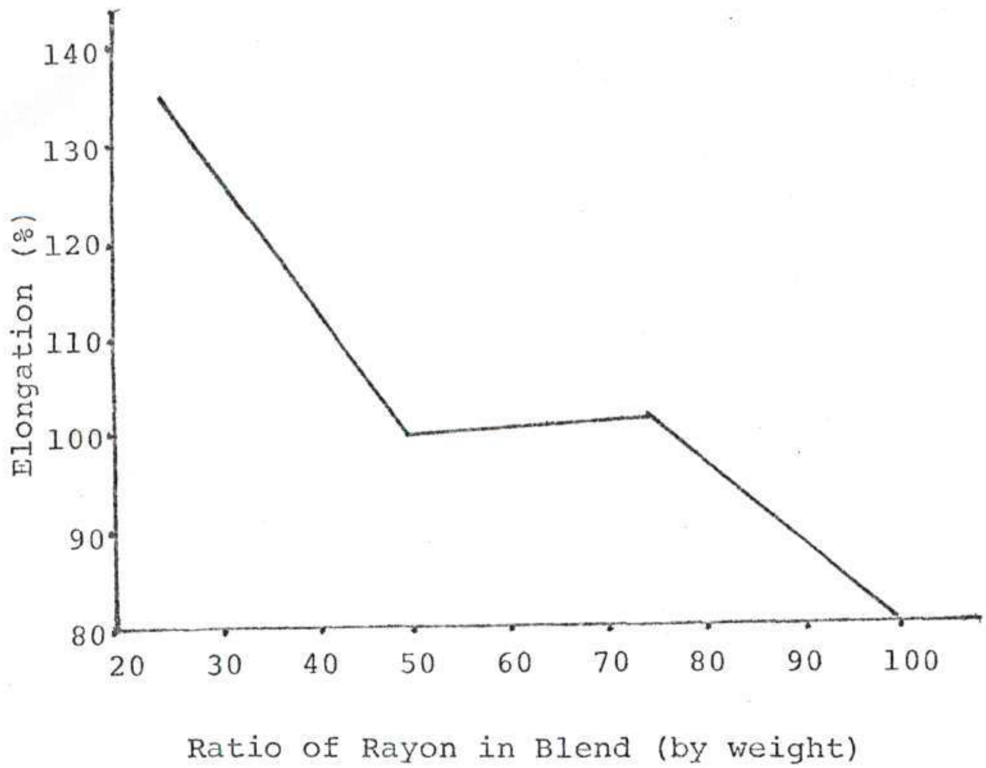

Figure III-3. Elongation of Rayon/Polyester Nonwoven Webs After Needle Punching (170 Needle Punches/ Sq.In) and Before Zinc Chloride Treatment

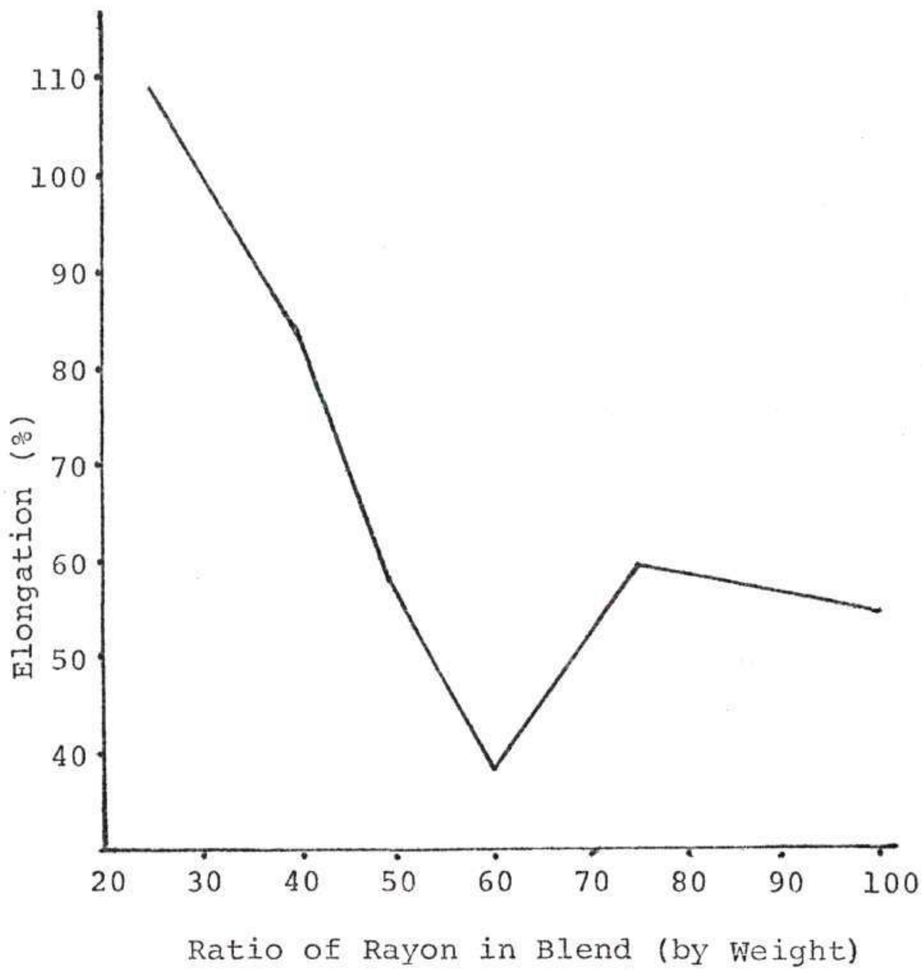

Figure III-4. Elongation of Rayon/Polyester Nonwoven Webs After Zinc Chloride Treatment

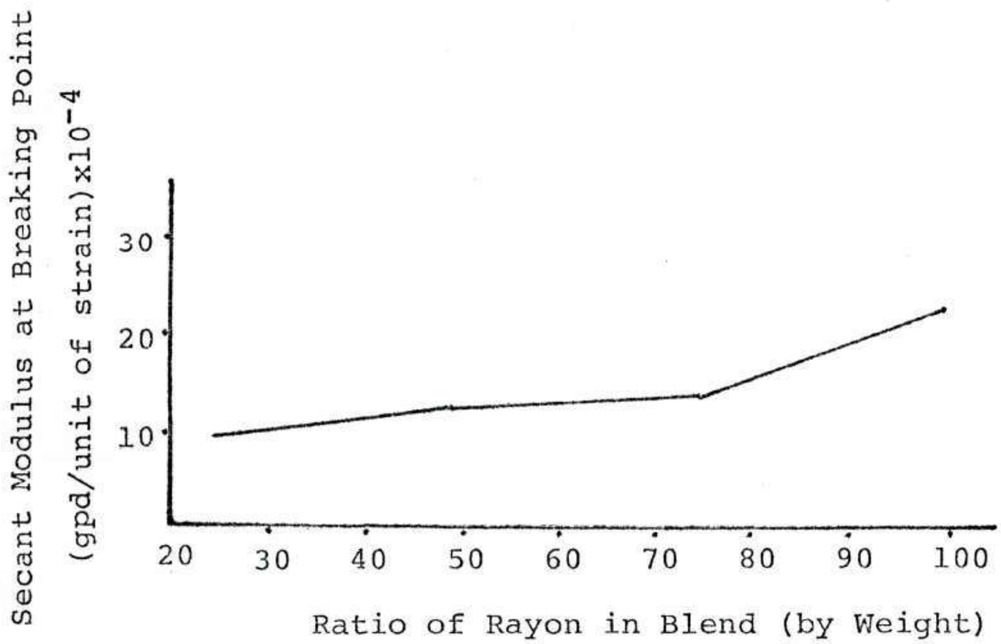

Figure III-5. Secant Modulus at Breaking Point of Rayon/Polyester Nonwoven Webs After Needle Punching (170 Needle Punches/In^2) and Before Zinc Chloride Treatment

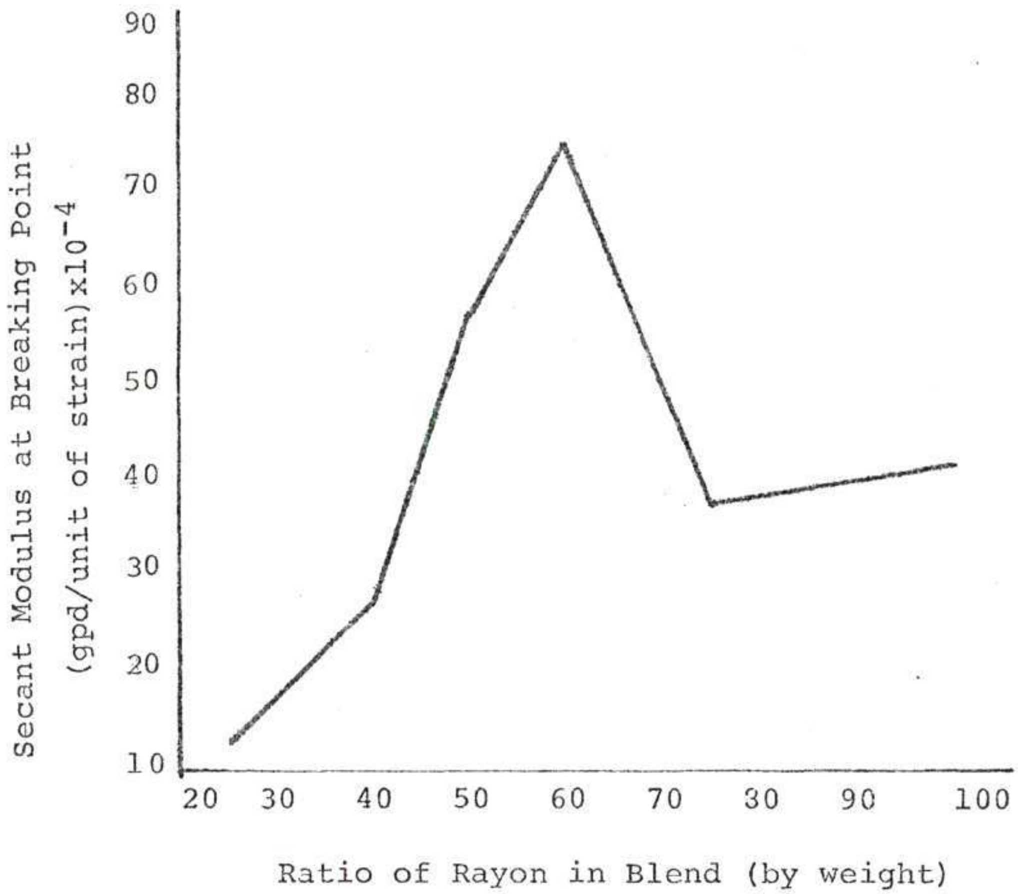

Figure III-6. Secant Modulus at Breaking Point of Rayon/Polyester Nonwoven Webs After Zinc Chloride Treatment

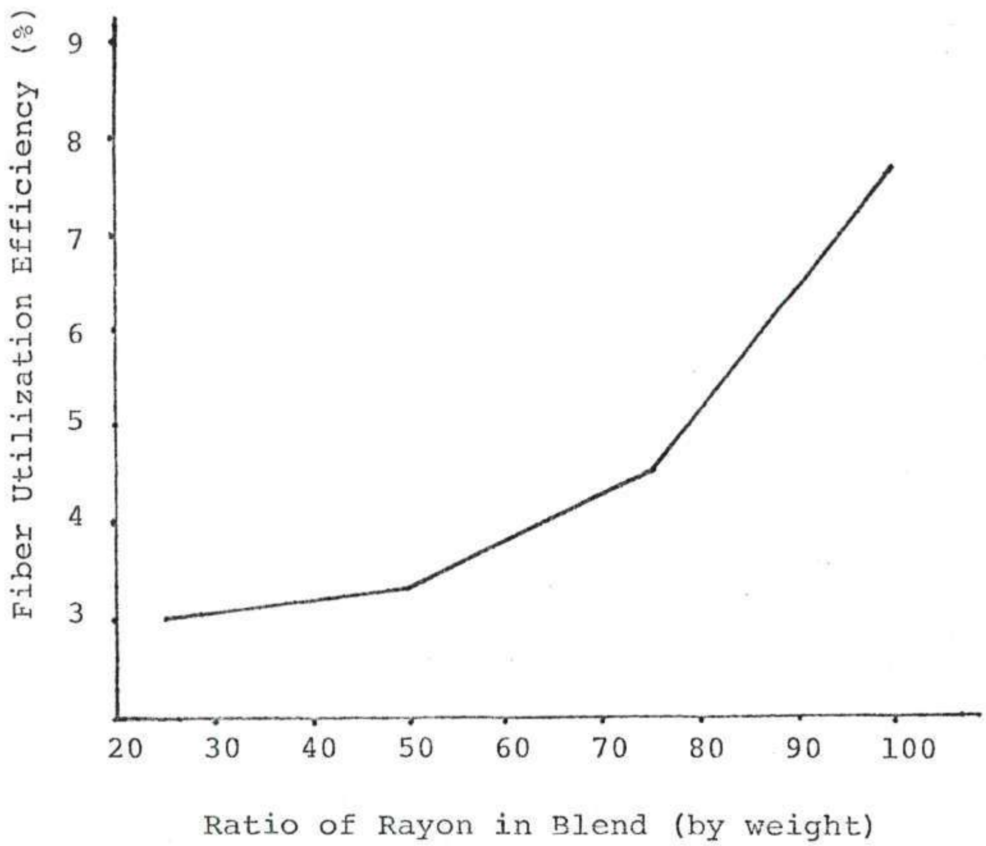

Figure III-7. Fiber Utilization Efficiency in Rayon/Polyester Nonwoven Webs After Needle Punching (170 Needle Punches/In^2) and Before Zinc Chloride Treatment

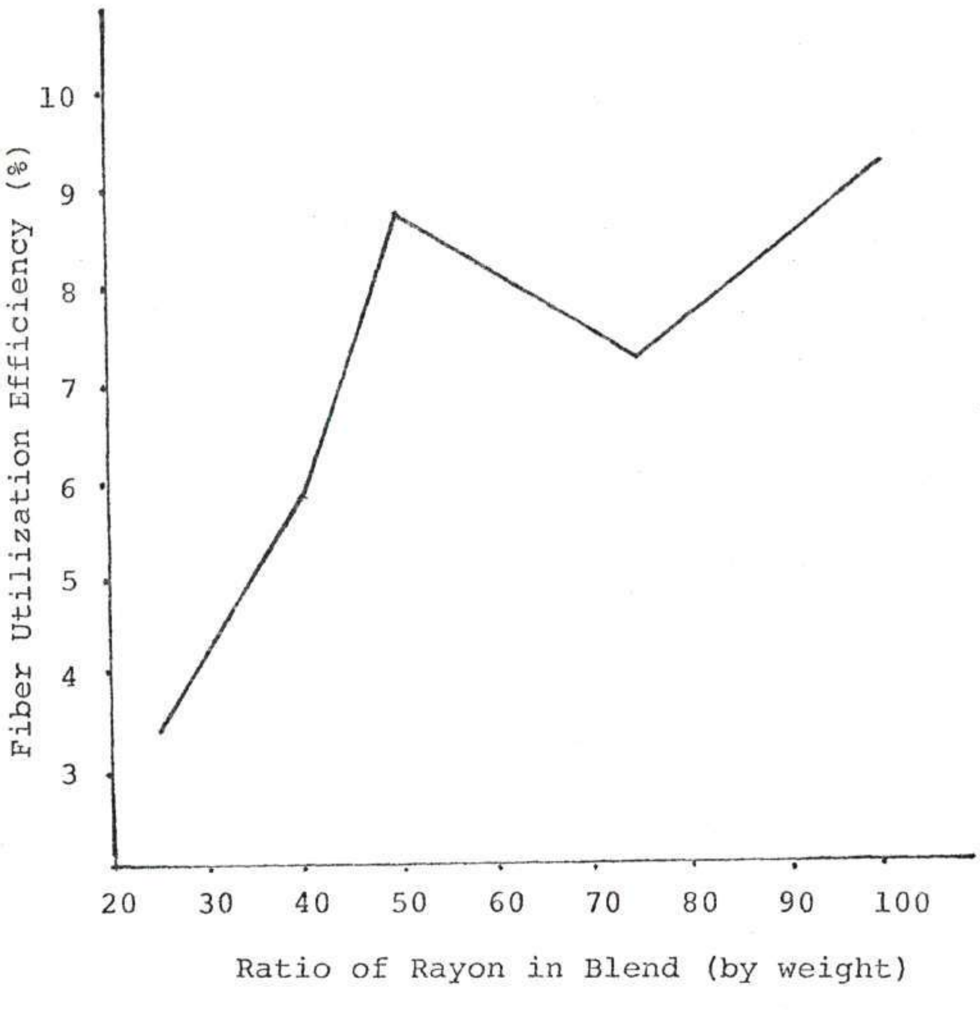

Figure III-8. Fiber Utilization Efficiency in Rayon/Polyester Nonwoven Webs After Zinc Chloride Treatment

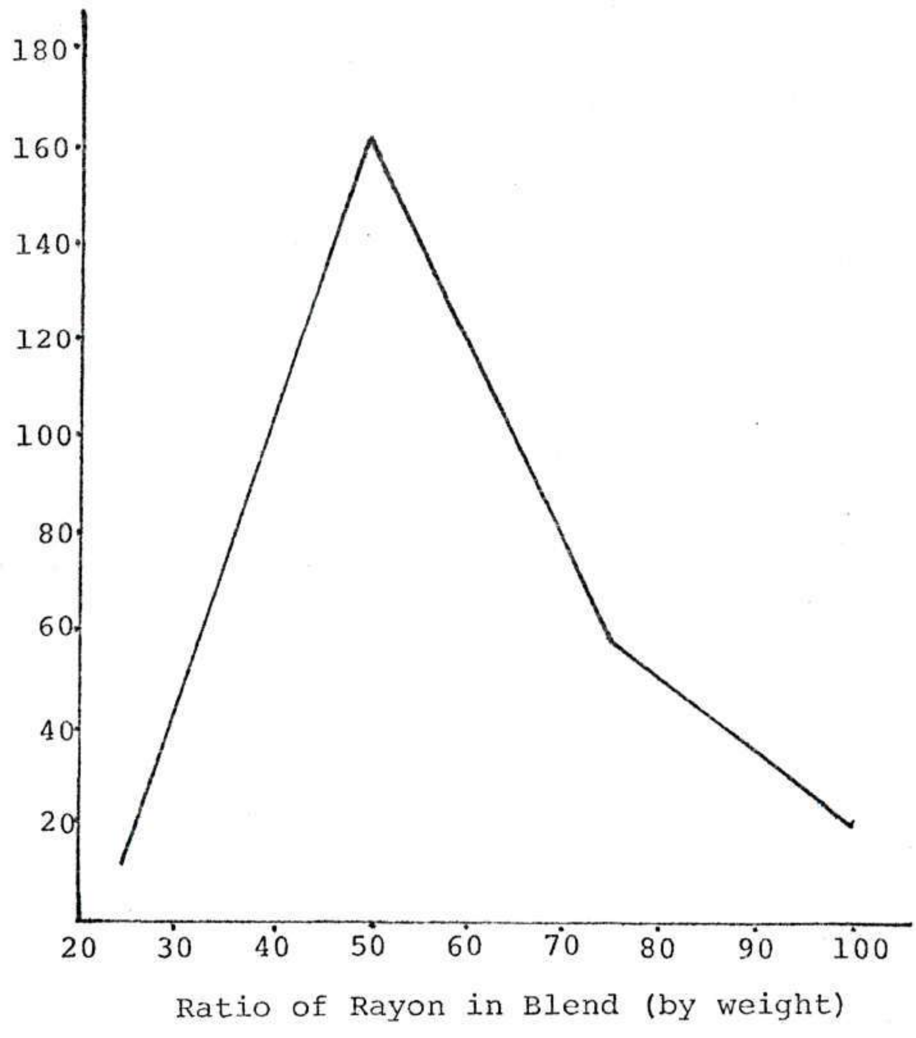

Figure III-9. Percentage Change in Tenacity of Rayon/Polyester Nonwoven Webs Due to Zinc Chloride Treatment

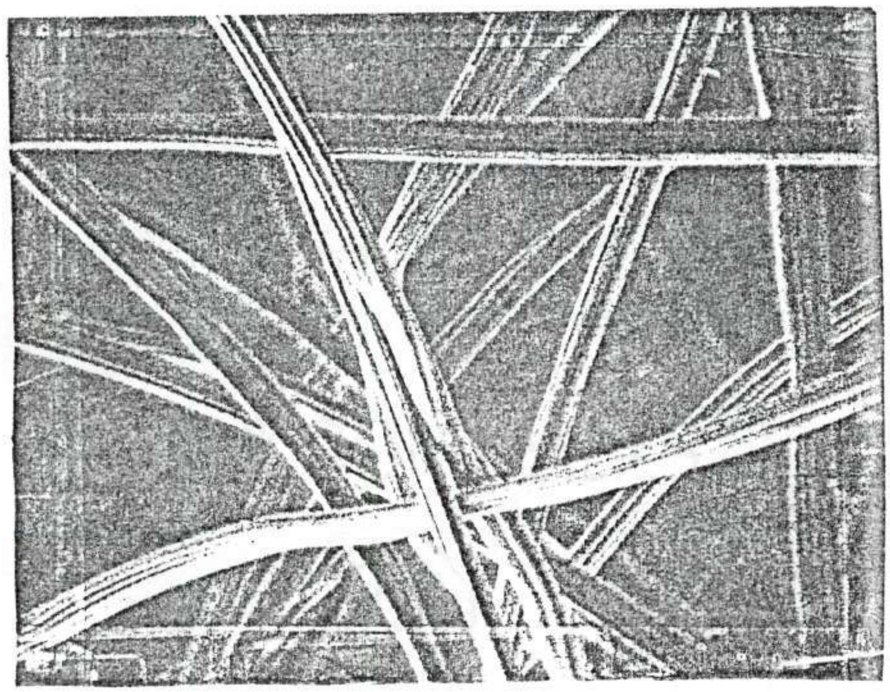

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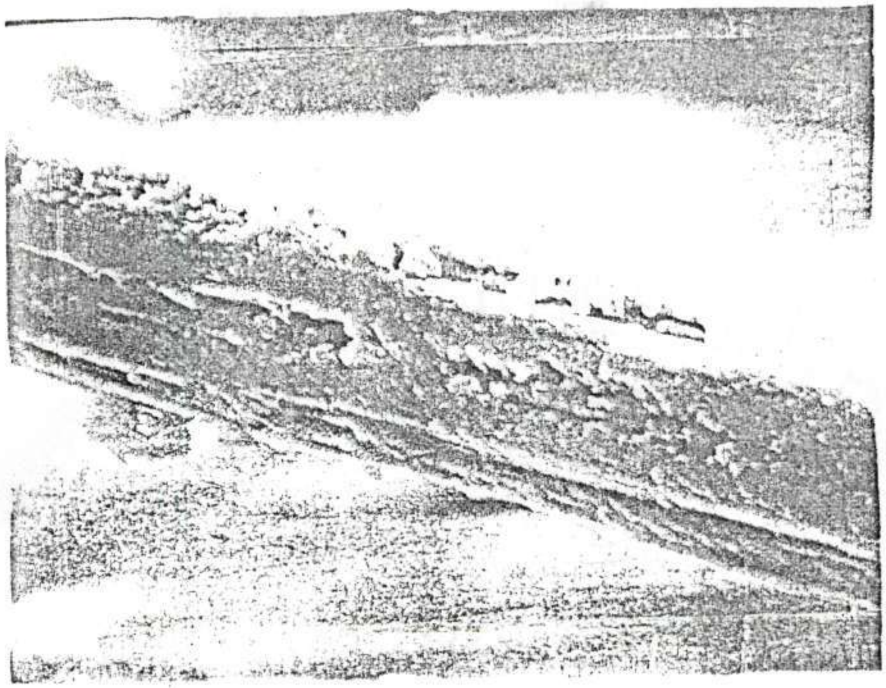
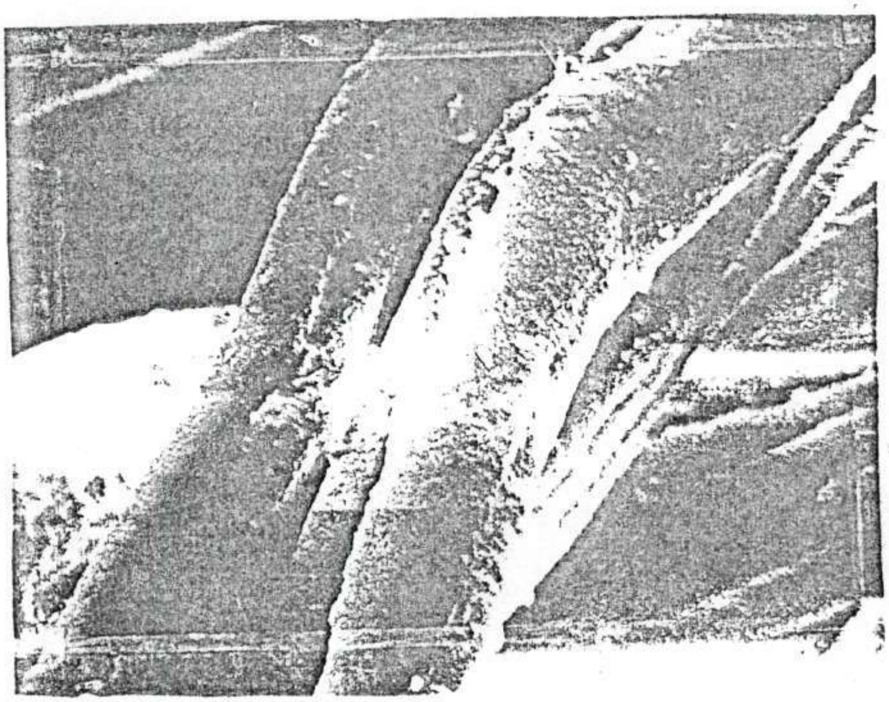
Figure III-10. A Scanning Electron Photomicrograph of Rayon Fibers Before Zinc Chloride Treatment



(a) (3000x)



(b) (3000x)

Figure III-11. A Scanning Electron Photomicrograph of Rayon Fibers After Zinc Chloride Treatment

CHAPTER IV

DISCUSSION OF RESULTS AND CONCLUSIONS

The data of web tenacity, breaking elongation, secant modulus at break point, and fiber utilization efficiency of the various blends after needle punching indicate that the viscose rayon fibers used have a higher fiber-to-fiber coefficient of friction than the polyester fibers, and, therefore, fiber entanglements achieved by needle punching become more effective and slip resistant as the percentage of rayon in blend is increased. This hypothesis is, in particular, confirmed by the monotonic significant increase in fiber utilization efficiency as the percentage of rayon fibers in the blend is increased, as shown in Figure 111-7.

On the other hand, the zinc chloride treated webs data indicate that the polyester fibers contribute significantly to the web load-carrying mechanism when two conditions are met, namely; (1) the percentage of rayon in blend is sufficiently high to effect a locking action onto the polyester fibers, and (2) the product of polyester fiber tenacity and percentage in blend is higher than that of rayon. In this work, the polyester fibers have a much higher tenacity (approximately 100% higher) than the rayon fibers. Based on the data shown in Figure III-9, it is reasonable to conclude that the polyester fiber contribution to the load-carrying mechanism is optimum when the polyester/rayon blend ratio is 1:1. At this blend ratio, the percentage change in web tenacity due to zinc chloride treatment is highest, (approximately 160%). In addition, blends containing more than 50% rayon fibers did not show significant changes in fiber utilization efficiency, in comparison to the 50/50 blend. This could possibly indicate that even though the number of bondable fibers present in these blends is significantly higher, the final overall fiber utilization efficiency in web is unaffected due to some fiber damage, (see Figures III-10 and III-11), caused by the zinc chloride treatment.

In summary, it appears that the mechanism of tensile rupture of the investigated bonded webs incorporate two types of failure, namely: cohesive failure and interfiber slippage, the proportion of each depends on the percentage of bondable fibers in the blend. At one extreme, when the percentage of bondable fibers in web is 100, (i.e., an all rayon web), the rupture mechanism is one of cohesive failure as evidenced by the low breaking elongation and high fiber utilization efficiency data of bonded 100% rayon web shown in Figures III-4 and III-8 respectively. On the other hand, when the percentage of bondable fibers in the blend is low, inter-fiber slippage becomes the dominating mode of failure, as evidenced by the low tenacity, high elongation, low modulus, and low fiber utilization efficiency data of the 25% rayon / 75% polyester web shown in Figures III-2, III-4, III-6 and III-8.

APPENDIX A

DETAILED DATA

Table A-1. Tensile Load-Elongation Data of Single Rayon Fibers

Test Specimen No.	Breaking Tenacity (g/d)	Elongation (%)	Initial Modulus (g/d)
1	1.73	21.4	34.72
2	2.93	19.6	41.67
3	2.03	18.2	32.05
4	2.47	17.4	41.67
5	2.37	18.0	43.86
6	1.30	16.0	27.78
7	2.30	21.4	41.67
8	2.45	20.0	41.67
9	2.41	22.8	26.88
10	1.67	19.6	24.51
11	2.33	18.0	41.67
12	2.55	25.6	27.78
13	2.57	16.0	33.33
14	2.30	18.0	41.67
15	2.37	21.4	27.78
16	1.90	12.2	41.67
17	2.70	19.6	26.04
18	2.77	10.0	41.67
19	2.70	18.0	41.67
20	2.52	15.8	28.73
21	2.39	17.6	43.86
22	2.60	14.0	43.86
23	2.53	19.6	41.67
Ave.	2.45	19.12	38.26

Table A-2. Tensile Load-Elongation Data of Single Polyester Fibers

Test Specimen No.	Breaking Tenacity (g/d)	Elongation (%)	Initial Modulus (g/d)
1	5.23	64.6	32.05
2	4.77	54.0	33.33
3	4.77	52.6	24.88
4	5.13	84.0	26.04
5	4.40	58.0	30.30
6	4.67	61.6	23.81
7	4.67	43.0	47.62
8	3.93	40.6	23.81
9	4.80	35.0	33.33
10	5.20	75.0	23.81
11	4.77	77.4	25.25
12	5.00	77.6	37.88
13	4.63	67.0	19.61
14	4.67	81.0	40.65
15	4.63	63.0	41.66
16	4.87	61.0	34.01
17	4.50	60.0	30.30
18	4.97	58.0	55.56
19	4.40	44.0	27.78
20	4.50	72.0	41.66
21	4.87	56.0	33.33
22	5.43	60.0	30.30
Ave.	5.01	61.49	33.97

Table A-3. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 6 Web, After Needle Punching

(Blend No. 6: 25% Rayon / 75% Polyester)

Test Specimen No.	Weight of (3"x6") Test Specimen (gms)	Web basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gms/denier	Elongation (%)
1	0.78	1.98	3.75	0.11	161
2	0.78	1.98	4.50	0.13	123
3	0.70	1.78	4.65	0.15	163
4	0.78	1.98	4.35	0.13	150
5	0.78	1.98	3.95	0.12	142
6	0.78	1.98	3.60	0.11	113
7	0.78	1.98	3.70	0.11	108
8	0.70	1.78	6.00	0.20	122
Ave.				0.1325	135

Table A-4. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 4 Web, After Needle Punching

(Blend No. 4: 50% Rayon / 50% Polyester)

Test Speci-men No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenac-ity (gms/denier)	Elonga-tion (%)
1	0.55	1.40	2.05	0.09	87
2	0.60	1.52	2.75	0.11	100
3	0.60	1.52	3.20	0.12	118
4	0.60	1.52	2.30	0.09	98
5	0.62	1.57	4.45	0.17	105
6	0.75	1.90	5.25	0.16	95
7	0.60	1.52	2.95	0.11	113
8	0.65	1.65	4.15	0.15	87
Ave.				0.125	100

Table A-5. Basis Weight, Grab Test Strength, Tenacity, and Elongation of Blend Number 2 Web, After Needle Punching

(Blend No. 2: 75% Rayon / 25% Polyester)

Test Specimen No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gms/denier)	Elongation (%)
1	0.70	1.78	6.65	0.22	102
2	0.70	1.78	3.80	0.13	105
3	0.75	1.90	4.25	0.13	93
4	0.75	1.90	4.82	0.15	143
5	0.70	1.78	4.30	0.14	110
6	0.70	1.78	3.45	0.11	108
7	0.70	1.78	4.15	0.14	82
8	0.70	1.78	3.30	0.11	74
Ave.				0.141	102

Table A-6. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 1 Web, After Needle Punching

(Blend No. 1: 100% Rayon / 0% Polyester)

Test Speci-men No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenac-ity (gms/denier)	Elonga-tion (%)
1	0.65	1.65	4.60	0.16	67
2	0.65	1.65	4.20	0.15	66
3	0.80	2.03	8.85	0.26	77
4	0.80	2.03	9.60	0.28	113
5	0.60	1.52	3.70	0.14	99
6	0.70	1.78	5.65	0.19	79
7	0.70	1.78	4.70	0.16	67
8	0.65	1.65	4.50	0.16	80
Ave.				0.1875	81

Table A-7. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 6 Web, After Zinc Chloride Treatment

(Blend No. 6: 25% Rayon / 75% Polyester)

Test Specimen No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gms/denier)	Elongation (%)
1	0.75	1.90	3.60	0.11	103
2	0.75	1.90	11.1	0.34	118
3	0.70	1.78	3.70	0.12	116
4	0.65	1.65	2.60	0.09	120
5	0.70	1.78	7.70	0.25	102
6	0.75	1.90	4.70	0.15	109
7	0.60	1.52	2.80	0.11	102
8	0.50	1.27	2.00	0.09	117
9	0.50	1.27	1.80	0.08	97
Ave.				0.1489	109

Table A-8. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 5 Web, After Zinc Chloride Treatment

(Blend No. 5: 40% Rayon / 60% Polyester)

Test Specimen No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gm/denier)	Elongation (%)
1	0.85	2.16	8.70	0.237	110
2	0.85	2.16	16.0	0.436	77
3	0.75	1.90	7.80	0.241	88
4	0.85	2.16	4.80	0.131	68
5	0.90	2.28	8.80	0.227	108
6	0.75	1.90	6.20	0.192	77
7	0.80	2.03	6.10	0.177	61
Ave.				0.234	841

Table A-9. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 4 Web, After Zinc Chloride Treatment

(Blend No. 4: 50% Rayon / 50% Polyester)

Test Specimen No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gm/ denier)	Elongation (%)
1	0.60	1.52	7.90	0.31	67
2	0.65	1.65	8.30	0.30	66
3	0.65	1.65	8.40	0.30	54
4	0.70	1.78	13.0	0.43	92
5	0.75	1.90	11.40	0.35	33
6	0.75	1.90	8.70	0.27	32
Ave.				0.327	57.3

Table A-10. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 3 Web, After Zinc Chloride Treatment

(Blend No. 3; 60% Rayon / 40% Polyester)

Test Specimen No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gm/denier)	Elongation (%)
1	0.80	2.03	9.20	0.27	38
2	0.95	2.41	8.80	0.21	33
3	1.20	3.04	17.6	0.34	27
4	0.70	1.78	7.70	0.25	35
5	0.70	1.78	6.0	0.20	45
6	0.70	1.78	7.0	0.23	51
7	1.00	2.54	13.0	0.30	35
8	0.80	2.03	12.70	0.37	23
9	0.80	2.03	10.60	0.31	40
10	0.85	2.16	12.90	0.35	53
Ave.				0.238	38

Table A-11. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 2 Web, After Zinc Chloride Treatment

(Blend No. 2: 75% Rayon / 25% Polyester)

Test Specimen No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gms/denier)	Elongation (%)
1	0.65	1.65	6.10	0.22	58
2	0.75	1.90	6.10	0.19	64
3	0.70	1.78	6.70	0.22	49
4	0.70	1.78	6.30	0.21	60
5	0.70	1.78	10.0	0.33	48
6	0.70	1.78	7.10	0.23	46
7	0.65	1.65	8.40	0.30	55
8	0.50	1.27	3.20	0.15	67
9	0.65	1.65	4.50	0.16	90
Ave.				0.2233	59.7

Table A-12. Basis Weight, Grab Test Strength, Tenacity and Elongation of Blend Number 1 Web, After Zinc Chloride Treatment

(Blend No. 1; 100% Rayon / 0% Polyester)

Test Speci-men No.	Weight of (3"x6") Test Specimen (gms)	Web Basis Weight (oz/sq.yd)	Grab Strength (lbs)	Web Tenacity (gm/ denier)	Elonga-tion (%)
1	0.95	2.41	10.90	0.27	53
2	0.75	1.90	5.30	0.16	59
3	0.70	1.78	3.68	0.12	72
4	0.70	1.78	9.20	0.30	50
5	0.90	2.28	10.0	0.26	55
6	0.95	2.41	9.10	0.22	62
7	0.65	1.65	6.90	0.25	30
Ave.				0.2257	54.4

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