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The Strength Effects of Saturating Paper Containing Synthetic Fiber

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Abstract

One of the most important objectives in the papermaking process is to produce paper with good strength properties. Some specialty paper grades need strength properties which exceed those attainable when only wood fiber is present in the final product. To achieve the additional strength, various additives and fibers can be added to the furnish, or supplementary processes can be performed on the paper. The objective of this thesis was to determine the strength effects of saturating paper containing nylon stock, and to attempt to correlate the strength relationship between the two strength enhancing parameters.

To observe the effects of nylon fiber properties, standard paper samples were produced with three different levels of nylon addition; 0, 15, and 30%. The amount of latex added to the sheets by the saturation process was also varied, to determine the latex bonding effects on strength.

The results of the experimentation showed that both the tear strength and the stretching ability of paper increased when nylon was added to the furnish. The tensile and burst strength of the paper was found to decrease with nylon addition, however. The nylon addition was also found to significantly decrease sheet formation, which affected testing results. The improved bonding created by the saturation process was found to increase all the strength properties tested, with burst strength showing the largest improvements. Before implementing either procedure, a careful cost versus property improvement analysis must be completed in order to determine if their use would truly be beneficial.

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Introduction

As the paper industry continues to gain knowledge and technology, the demand for higher performance, more versatile paper grades also continues to grow. With the development of new man-made fibers, binders, and techniques, papermakers have been consistently able to meet these increasing standards.

Obtaining high paper strength is one of the most important objectives in the paper making process. Some specialty paper grades need strength values which exceed those attainable when only wood fiber is present in the final product. To achieve the additional strength, various additives and fibers can be added to the wood furnish. Additional processes can be performed on the paper to improve strength properties as well.

The thesis procedure primarily involved adding nylon to a typical wood furnish, and then saturating the paper with a latex rubber. This was done to investigate the effects of both strength enhancing variables, and to attempt to correlate the relationship between the two.

Theory and Background

Synthetic Fiber Addition:

By utilizing synthetic fibers, advantages such as dimensional stability, resistance to water, resistance to rot and chemicals, certain strengths, and some printing applications can be gained in paper grades. These features must be balanced against product cost and problems which can arise in runnability and other paper properties, however (5). Thorough research is therefore needed before a decision is made on whether or not to use a synthetic fiber in a pulp. The type of synthetic fiber which should be used depends on what properties are needed in the paper product.

Nylon, which is known for its abrasion resistance and flex endurance, was the synthetic fiber investigated in this thesis. Nylon is a synthetic linear polyamide, consisting of repeating amide groups held together by a reactant. There are basically two types of nylon, nylon 6 and nylon 66. Nylon 66, which was used for the thesis project, has six carbon atoms in each reactant and is considered to be the stronger of the two types (2).

When purchasing nylon, the fiber length and diameter can also be specified. The lengths vary from about .25 inch to .75 inch. Shorter lengths permit better sheet formation, while longer lengths show better improvements in certain strength properties. Longer nylon fibers, which will show strength trends better, were used in the thesis. When choosing fiber diameter, a term called "denier" is used. Denier is defined as the weight in grams of 9000 m. of yarn. The diameter of a nylon fiber is proportional to the square root of the denier (2). For optimum physical properties, the following equation is used to determine denier: fiber length (inches) = .2 $(\text{denier})^{.5}$.

The following table shows a comparison of nylon fiber to wood cellulose fiber (1):

Property	Cellulose	Nylon
Length	< .2 inches	.25 to .75 inches
Diameter	16 - 40 um	variable
Density	1500 kg/m^3	1000 kg/m^3
Specific Stiffness	1300 - 4000 km	1000 km
Breaking Length	150 km	100 km

As can be seen by the table, nylon holds several advantages over cellulose fibers. First, they can be up to three times longer than softwood fibers. Longer fibers contribute to greater pulp strength, especially tear, which is virtually proportional to length (3). Another advantage is that nylon is a lighter material, as can be seen by observing the densities. This is important for improving the strength of light weight paper grades. As will be demonstrated later, a lower density also helps to improve tear and tensile strength. One more benefit is that it is more flexible than cellulose, as can be seen by the much lower specific stiffness values. Greater flexibility increases fiber bond sites, and improves some strength properties.

Nylon does have several disadvantages, however. First, and foremost, is that nylon costs much more than wood does. By observing the breaking length comparison, it can be seen that nylon is also slightly weaker than cellulose is. This number is misleading, however, the main reason the nylon shows the lower breaking length is that it is roughly three times longer than cellulose.

The major drawback nylon addition generates is poor bonding ability. With cellulose pulps, fiber-to-fiber bonding is amply formed by refining the pulp, and then forming and drying the web. Due to the fibrillous structure of wood fibers, the mechanical beating action of the refiner frays the fibers, thus greatly increasing the bond contact area of them. Also, the chemical relationship of cellulose with water produces hydrogen bonding between the fibers at contact points with the removal of water (10). These hydrogen bonds are surprisingly strong, although the addition of water to the sheet destroys them.

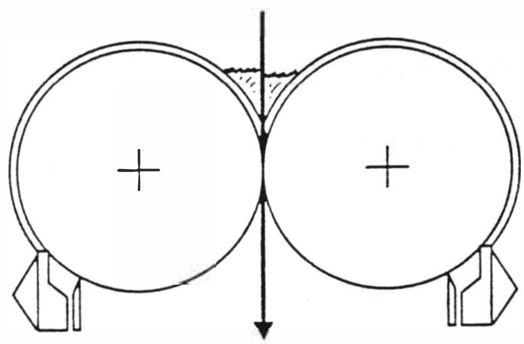
Nylon fibers, however, do not fray when subjected to refining. Their chemical structure does not allow them to form hydrogen bonds with the simple removal of water, either. This lack of bonding ability is not only seen in nylon-to-nylon bonding, but nylon fibers get between cellulose fibers in the web and interfere with cellulose bonding. Other methods of bonding must therefore be employed to successfully utilize the strength potential that nylon has to offer.

When nylon is used in a furnish, there are several process considerations which a mill must attend to. First, nylon is difficult to disperse. It resists wetting and has a foaming tendency when subjected to stirring. It must therefore be added in uniform, small quantities to the pulp slurry, not in one simple load addition. The slurry should also be pumped at lower consistencies, to help reduce the entanglement of the longer fibers, creating fiber flocculation. Operating at lower consistencies will also help to reduce the chance of pump, screen, or cleaner plugging which may occur with the long nylon fibers.

Saturation Process:

As previously discussed, there is little bonding between the synthetic and wood fibers, therefore a binder is added to tie the two together and to allow the nylon to contribute its strength abilities (2). The binder is added by saturating, or impregnating, the formed web with a polymer dispersion, or saturant.

The saturation process is performed through a size press, and can be performed on- or off-line in the industry. The following diagram illustrates the working mechanisms in the saturation process (8):



The web first runs through a flooded nip, filled with a saturation formula containing some type of binding latex. The saturated web then proceeds through the nip, where the excess saturant is squeezed out. At this point, the latex is still dispersed in the water in the sheet as fine particles. As the web continues out of the size press and moves over the dryer cans, it begins to heat up. When the sheet reaches temperatures over 115° F, the latex melts and adheres itself to the nylon and wood fibers (6), thus creating the necessary bonding between fibers. Not only can this process create fiber-to-fiber bonds, but it can protect existing natural bonds as well, and hence promote even stronger wet strength (9).

The amount of binder added to the sheet is referred to as pick-up, and is defined as the percentage of rubber weight to fiber weight. There are several factors which affect pick-up, including; sheet porosity, residence time in saturant, nip pressure, and saturant solids concentration. Since the amount of rubber retained in the sheet is proportional to the saturant dilution level, the industry uses solids concentration to obtain varying target pick-up values. Dilution level was used to control pick-up during the thesis experimentation, as well.

Experimental Design

Given the preceding background material, utilization of nylon fiber and the saturation process should impart additional strength properties, unobtainable with traditional papermaking. To observe the strength effects of the synthetic fiber and the binder addition, both were independently varied in standard paper samples.

The base stock used in the experimentation was a 75% softwood - 25% hardwood mix, supplied by the Western Michigan Pilot Plant. 120 g/m^2 basis weight sheets were made on Noble and Wood handsheet makers (5 g. - 8.5 x 8.5 inch sheets). Due to expected formation problems at the higher synthetic addition levels, a +/- .5 g. limit was set for acceptable handsheets.

Sheets were made at nylon levels of 0%, 15%, and 30%, by furnish weight. The synthetic fiber was added before refining, to ensure sufficient mixing of the two furnishes. A Valley laboratory beater was used in all runs, and the stock was refined to a level of 500 ml Canadian Standard Freeness. A proportionator was also used to keep the pulp dispersed before sheet formation in the Noble and Wood. Following formation, the sheets were pressed once at ten pound pressure, and then dried at 225° F on a laboratory dryer can. The sheets were then conditioned for one day to Tappi Standards, before they were saturated or tested.

The saturant used in this thesis was a styrene butadiene latex, Dow DL-219. To obtain varying pick-up levels, the saturant was diluted down to levels of 20/80, 50/50, and 80/20 % saturant to % water. The sheets were saturated by hand dipping them in the latex solution. They were then passed through the laboratory press with a rubber mat, to simulate the size nip and remove excess latex. The sheets were then dried once again on the laboratory dryer can.

Before being tested, the saturated sheets were once again allowed to condition to Tappi

Standards for one day. The sheets were weighed before and after saturating, so pick-up values could be determined. The latex pick-up was determined on a "dry" weight basis. A 6.3% moisture content was used in calculating base sheet bone-dry weight. Since the latex does not consume any water weight, the saturated bone dry weight was found by subtracting the base moisture weight from the saturated conditioned weight.

The 0%, 15%, and 30% synthetic sheets were tested at all three pick-up levels and with no latex added. Nine handsheets were tested for all twelve runs. The strength tests performed included tear, tensile, burst, and stretch. All tests were performed in Western Michigan University's laboratories on equipment calibrated to Tappi Standards.

PROCEDURE SUMMARY:

1.) 120 g/m^2 basis weight sheets were made on a Noble and Wood handsheet maker.

2.) The percent nylon added to the sheets was varied at 3 levels:

a.) 0 %
b.) 15 %
c.) 30 %

3.) The sheets were saturated at 3 different dilution levels:

a.) 20% SBR/ 80% water
b.) 50% SBR/ 50% water
c.) 80% SBR/ 20% water

4.) Testing - Each synthetic level was tested at all 3 pick-up levels and with no latex added.

a.) Tear Index
b.) Tensile Index
c.) Burst Index (both sides)
d.) Stretch

Data and Discussion

Results:

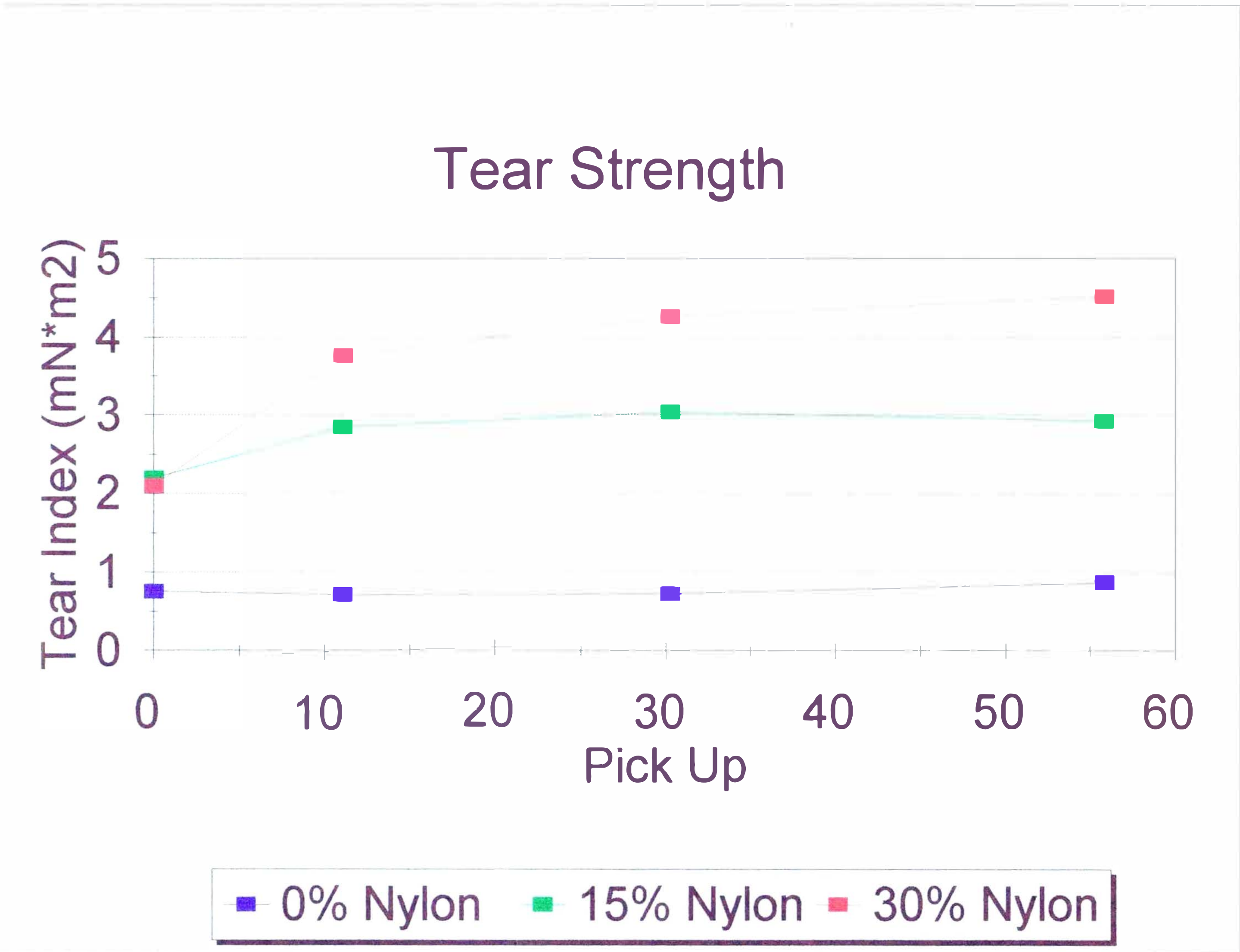
Pick Up	Tensile Index (Nm/g)	Stretch (%)	Tear Index (mN*m2/g)	Burst Index (Wire)	(Kpa*m2/g) (Felt)	Average
No nylon						
0	64.42	3.13	.76	82.83	80.42	81.63
8.3	71.54	5.10	.72	80.36	90.33	85.35
31.7	77.40	5.72	.74	105.06	104.89	104.98
58.4	76.75	6.21	.87	109.29	108.86	109.08
15% nylon						
0	45.28	3.61	2.20	52.75	51.25	52.00
9.98	47.80	4.13	2.85	69.00	64.89	66.95
26.04	51.75	5.22	3.04	87.71	87.14	87.43
51.48	60.53	10.51	2.93	104.00	104.00	104.00
30% nylon						
0	25.65	6.66	2.10	49.86	55.88	52.87
15.08	28.74	10.44	3.76	62.63	56.88	59.75
33.14	39.46	16.34	4.26	79.38	86.50	82.94
57.66	41.52	17.98	4.52	113.63	112.38	113.00

Formation Effects:

As the amount of nylon in the furnish increased, good formation became difficult to obtain, due to the length of the nylon fibers. During experimentation, each nylon level was given a formation number representing sheet uniformity. With a 5 being considered "satisfactory", the 0% nylon sheets were given an 8, the 15% sheets were given a 4, and the 30% nylon sheets were given a value of only 2. By observing the standard deviation of the strength results for each nylon level (Appendix I.), it can be seen that the 30% nylon results had a significantly larger deviation than the 100% cellulose furnish. This means that when the nylon level increased, the strength tests showed increasing variation in results. This is another indicator of poor sheet formation as a result of nylon addition.

The original objective of the thesis was to investigate the strength effects of varying the individual fiber strength and the bonding strength of the paper, by adding nylon and rubber in varying amounts to the sheets. The large variation in formation values between each nylon level introduced a third factor in obtaining paper strength, however: distribution of fibrous material through out the sheet.

This formation factor came to make a difference in each strength property. It's effects are analyzed along with the fiber and bonding strength effects in this section of the thesis.


Tear Strength
Tear Index (mN*m2)
0
1
2
3
4
5
0
10
20
30
40
50
60
Pick Up
0% Nylon
15% Nylon
30% Nylon

Tear Strength:

By observing the tear index graph on the previous page, it can be seen that the tear index increased proportionally as nylon was added to the furnish. A 15% increase in nylon addition contributed to a 100% increase in tear strength. This result was expected, since fiber length is the principle factor affecting tear strength.

James Clark has shown that the following relationship exists between length and tear (3);

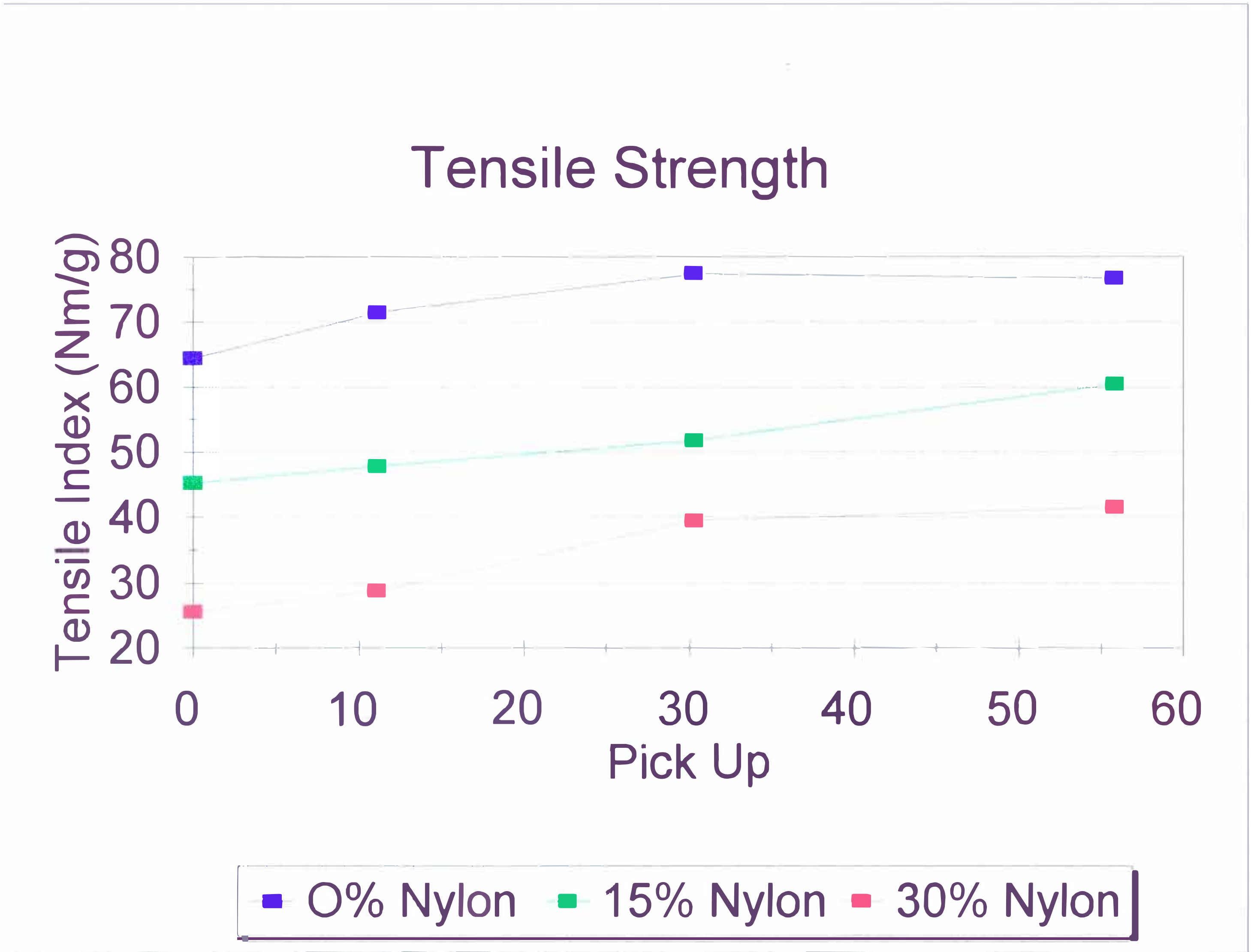
$$\text{Tear strength} = k\,\frac{L^{1.5}}{D}$$

: where k = constant, L = fiber length, and D = sheet density.

This equation clearly shows that the three times longer nylon fibers would significantly improve tear. The fact that the nylon fibers are approximately 33% lighter than their cellulose counterparts would decrease sheet density, and therefore also help increase tear strength.

It can also be seen from Clark's equation that bonding strength should have no effect on tear, which is a measurement of fiber characteristics. The saturation process should, therefore, not effect the tear index either. The 15 and 30% nylon addition tear curves, show different trends, however. The reason for this tear increase with binder addition can most probably be attributed to formation problems.

During the Elmendorf tear test, the tear apex moves through the weakest path through the paper sample it is tearing (3). The poorer formation of the 15 and 30% nylon level sheets, means that there were more 'weak' spots in the sheets, which lowers the distance, and force, the tear must overcome to complete the test. The uniform addition of the latex during the saturation process, helps to "unify" the weak spots, by increasing the bonding of the few fibers in these regions. Thus a slight increase in tear would be seen with the addition of the SBR latex, due to the poor fiber distribution at the higher nylon addition levels.


Tensile Strength
Tensile Index (Nm/g)
80
70
60
50
40
30
20
0
10
20
30
40
50
60
Pick Up
O% Nylon
15% Nylon
30% Nylon

Tensile Strength

By viewing the graph showing the tensile index results, it can be seen that the tensile index linearly decreases as the nylon level is raised. These results were expected, and can best be described by analyzing Page's equation:

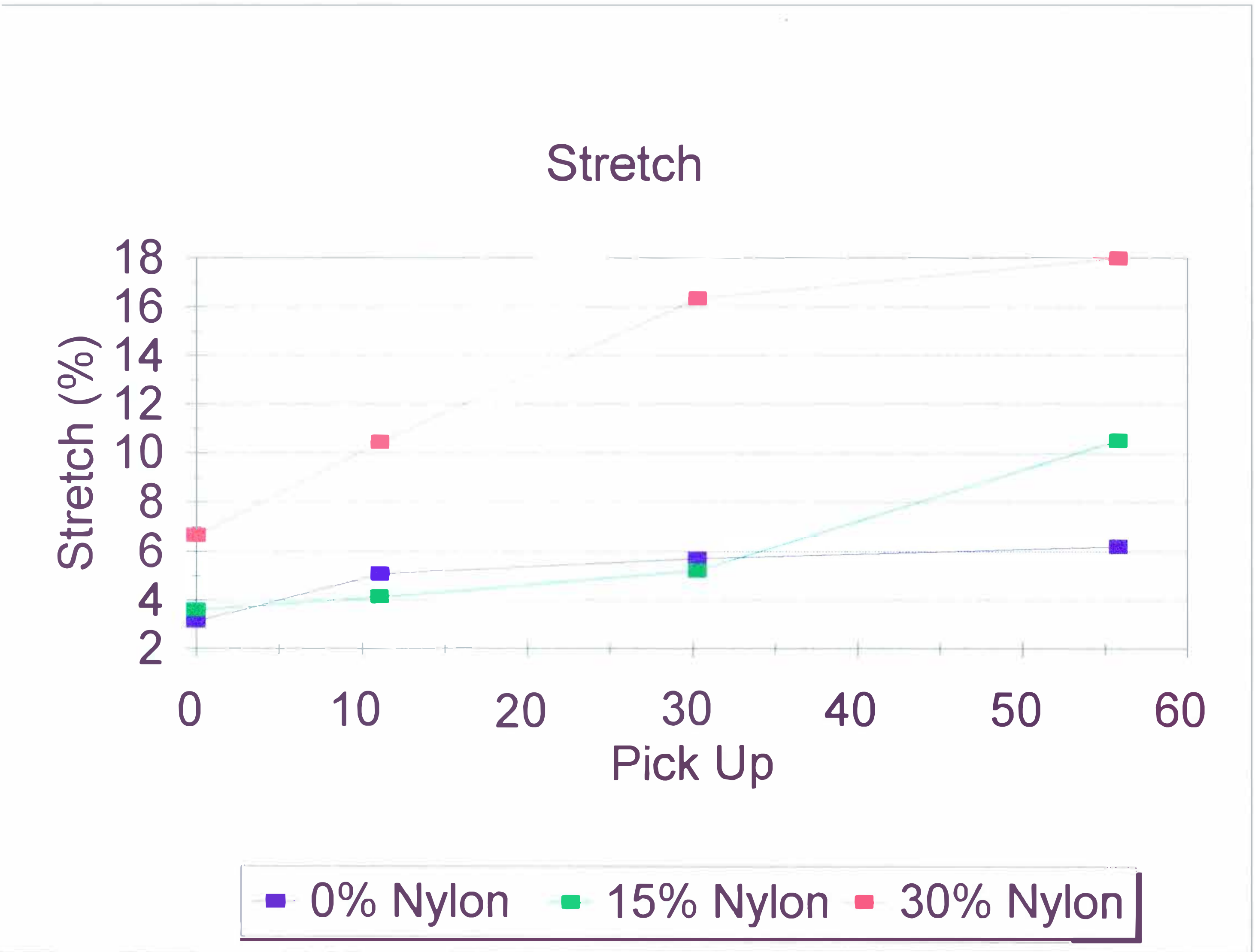
$$\frac{1}{T} = \frac{9}{8Z} + \frac{12\,A\,d\,g}{b\,P\,L\,(rba)}$$

T - Tensile strength
Z - Zero span tensile strength
A - Average fiber cross section
d - Density of fibrous material
g - Acceleration due to gravity
b - Shear bond strength
P - Perimeter of fiber cross section
L - Fiber length
(rba) - Relative bonded area of the sheet

From this equation, it can be seen that the extremely poor bonding ability of nylon would result in much lower tensile index values (reduction in b and rba). Since zero span tensile (Z) is a measure of individual fiber strength, the weaker nylon fibers would also contribute to further tensile reductions. The longer fiber length (L) and lighter density (d) of the nylon fibers do contribute some tensile strength. These contributions are largely overshadowed by the poor bonding and smaller breaking length of the nylon fibers, however.

The decrease in sheet formation, with the nylon addition, also plays a large role in the decreasing tensile indexes. The tensile test is performed on a long 15 mm. paper strip from the sheet sample. When the load is applied, the strip will break in the weakest portion of the strip. With the poor formation, the strip will break sooner in one of the low fiber regions, thus reducing tensile strength.

With latex addition, the graph shows increasing tensile values. This can be attributed to the improved bonding supplied by the saturant. The latex addition also helped to improve the strength of the weaker portions of the strip, caused by bad formation.

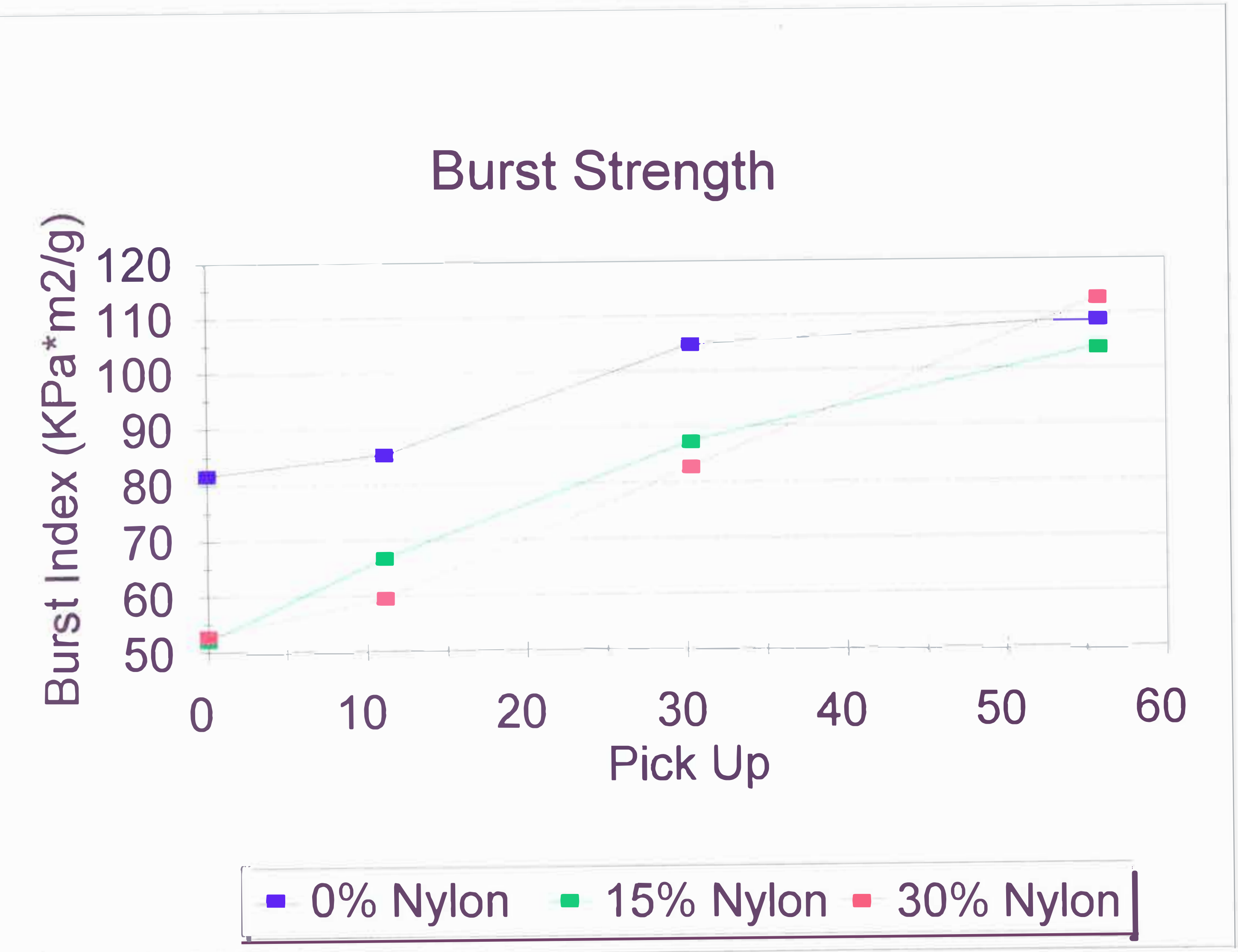


Stretch
Stretch (%)
18
16
14
12
10
8
6
4
2
0
10
20
30
40
50
60
Pick Up
0% Nylon
15% Nylon
30% Nylon

Stretch

The graph representing stretch characteristics of the tested sheets shows that the nylon fibers contributed to higher sheet elongation before rupture. During stretch testing, it was found that the nylon fibers were able to hold the strip together well enough for the tensile tester to continue taking stretch measurements, even though the strip had split, and the tensile readings stopped. The main reason for this is the extraordinary length of the nylon fibers.

When the amount of rubber was raised in the sheets, the stretch values were found to increase further. There are two main reasons for this occurrence. First, the binder improved the bond strength, allowing the strip to stretch further. This was especially apparent at the higher nylon levels where the additional bond strength allowed the tester to continue making measurements with only a few nylon fibers holding the strip together. With weaker bonding, the fibers would have slipped out of the strip and completed the test. The second reason is that rubber has the natural ability to stretch. The latex addition increased the amount of 'stretchable' bonding area in the test strips. Overall, nylon and latex addition both improved the stretchability of the paper.


Burst Strength
Burst Index (KPa*m2/g)
120
110
100
90
80
70
60
50
0
10
20
30
40
50
60
Pick Up
0% Nylon
15% Nylon
30% Nylon

Bursting Strength:

As can be seen by the burst index graph, the saturation process greatly improved the bursting strength of the paper samples. Burst strength is primarily a measure of sheet bonding, therefore these results were expected. The left axis of the graph, where no latex was added, is a good representation of the poor bonding ability of nylon fibers. When no rubber was present in the sheet, the bursting strength was cut almost in half when the nylon was added. At the higher rubber percentages, the bonding effects of the saturant outweighed the weaker fiber and bonding strength of the nylon, and all three curves showed similar results. If a paper grades primary requirement was bursting strength, the saturation process would therefore be a recommendable way to achieve this objective.

Conclusions

Nylon Addition

- At synthetic levels tested, nylon addition created lower tensile and burst strength values.
- Both tear strength and stretch values improve as nylon fiber is added to paper.
- Nylon addition significantly decreases sheet formation.

Saturation

- The saturation process improved all the strength properties which were tested in this thesis work. Burst strength and stretch showed the largest improvements with latex addition.

Summary:

The saturation process can be used to improve all paper strength properties. If high tear or stretch standards are required, nylon addition would be a recommended way of achieving them. Formation problems and low tensile and burst specs. must be closely monitored with the use of nylon, however.

Anytime the saturation process or nylon stock addition is being used in papermaking, their strength benefits must be carefully weighed against their increased costs, to determine if their use is actually beneficial.

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20. APPENDIX I.

No Synthetic, 80% SBR / 20% Water

No.	CD wt	SatCDwt	P.U.	B.W. (g/m2)		Tensile Load	Extension	Tear	Burst Wire	Felt
1.00	5.37	8.15	55.30	130.05		14.76	6.57	10.71	128.00	118.00
2.00	4.65	7.19	58.20	112.62		14.14	5.28	10.71	105.00	107.00
3.00	4.82	8.65	70.80	116.73		12.85	7.62	10.71	99.00	114.00
4.00	5.22	7.89	67.30	126.42		14.86	5.90	10.67	105.00	116.00
5.00	5.09	7.73	55.30	123.27		13.54	5.24	10.67	114.00	107.00
6.00	5.16	7.66	51.90	124.97		15.99	6.39	10.67	119.00	110.00
7.00	4.87	7.44	56.40	117.95	blistered					
8.00	4.77	7.14	53.00	115.52	blistered					
9.00	4.83	7.29	54.20	116.98		12.88	6.48	10.71	95.00	90.00
Average	**4.98**	**7.68**	**58.04**	**120.50**		**14.15**	**6.21**	**10.69**	**109.29**	**108.86**
Std. Dev.	**0.23**	**0.47**	**6.18**	**5.52**		**1.06**	**0.77**	**0.02**	**10.78**	**8.66**

Tensile Index (Nm/g) =	76.75
Tear Index (mN*m2/g) =	0.87
Stretch (%) =	6.21
Burst Index (KPa*m2/g) =	109.07

No Nylon, 20% SBR / 80% water

Run No.	**CD wt.**	**SAT wt**	**P. U.**	**B.W. (g/m2)**	**Tensile Load**	**Extension**	**Tear**	**Burst Wire**	**Felt**
1.00	5.09	5.54	8.80	123.27	14.23	5.26	9.50	99.00	92.00
2.00	5.38	5.77	7.30	130.30	16.09	5.69	9.33	92.00	99.00
3.00	4.90	5.34	8.90	118.67	12.80	5.02	8.67	small sample	
4.00	5.01	5.39	7.70	121.34	10.81	4.90	8.83	100.00	97.00
5.00	4.88	5.20	6.60	118.19	12.48	4.96	9.33	97.00	91.00
6.00	5.45	5.91	8.40	131.99	14.68	5.93	8.00	103.00	99.00
7.00	5.40	5.90	9.30	130.78	14.35	4.73	9.17	104.00	97.00
8.00	5.46	5.93	8.60	132.23	15.98	4.73	10.00	100.00	92.00
9.00	5.16	5.63	9.10	124.97	13.45	4.44	9.33	small sample	
10.00	5.08	5.54	9.00	123.03	11.16	4.46	9.00	97.00	97.00
11.00	4.85	5.27	8.80	117.46	14.12	5.93	9.00	92.00	85.00
Average	**5.19**	**5.62**	**8.30**	**124.75**	**13.65**	**5.10**	**9.11**	**80.36**	**94.33**
Std. Dev.	**0.22**	**0.25**	**0.81**	**5.44**	**1.65**	**0.52**	**0.49**	**41.41**	**3.24**

Tensile Index (Nm/g) =	**71.54**
Tear Index (mN*m2/g) =	**0.72**
Stretch (%) =	**5.10**
Burst Index (kPa*m2/g) =	**95.50**

No Nylon, 50% SBR / 50% water

Run No.	CD wt.	CD Sat wt	P.U.	B.W.(g/m2)	Tensile Load	Extension	Tear	Burst Wire up	Felt up
1.00	4.95	6.36	30.40	119.88	15.72	6.33	9.33	117.00	89.00
2.00	5.09	6.54	30.40	123.27	14.35	5.44	9.33	111.00	113.00
3.00	4.85	6.25	30.90	117.46	14.07	6.11	9.33	108.00	114.00
4.00	4.80	6.18	30.60	116.25	15.68	6.14	9.46	107.00	101.00
5.00	5.09	6.90	37.90	123.27				92.00	99.00
6.00	4.91	6.31	30.40	118.91	12.49	5.16	9.46	97.00	110.00
7.00	4.96	6.41	31.10	120.13	13.37	5.31	8.33	106.00	110.00
8.00	4.97	6.45	31.70	120.37	15.48	6.10	8.33	115.00	114.00
9.00	4.60	5.97	31.80	111.41	11.01	5.14	8.33	92.50	94.00
Average	**4.91**	**6.37**	**31.69**	**119.00**	**14.02**	**5.72**	**8.99**	**105.06**	**104.89**
Std Dev.	**0.14**	**0.24**	**2.25**	**3.46**	**1.57**	**0.47**	**0.51**	**8.71**	**8.85**

Tensile Index (Nm/g) = 77.04
Tear Index (mN*m2/g) = 0.74
Stretch (%) = 5.72
Burst Index (KPa*m2/g) = 104.97

No Synthetic, 80% SBR / 20% Water

No.	CD wt	SatCDwt	P.U.	B.W. (g/m2)		Tensile Load	Extension	Tear	Burst Wire	Felt
1.00	5.37	8.15	55.30	130.05		14.76	6.57	10.71	128.00	118.00
2.00	4.65	7.19	58.20	112.62		14.14	5.28	10.71	105.00	107.00
3.00	4.82	8.65	70.80	116.73		12.85	7.62	10.71	99.00	114.00
4.00	5.22	7.89	67.30	126.42		14.86	5.90	10.67	105.00	116.00
5.00	5.09	7.73	55.30	123.27		13.54	5.24	10.67	114.00	107.00
6.00	5.16	7.66	51.90	124.97		15.99	6.39	10.67	119.00	110.00
7.00	4.87	7.44	56.40	117.95	blistered					
8.00	4.77	7.14	53.00	115.52	blistered					
9.00	4.83	7.29	54.20	116.98		12.88	6.48	10.71	95.00	90.00
Average	**4.98**	**7.68**	**58.04**	**120.50**		**14.15**	**6.21**	**10.69**	**109.29**	**108.86**
Std. Dev.	**0.23**	**0.47**	**6.18**	**5.52**		**1.06**	**0.77**	**0.02**	**10.78**	**8.66**

Tensile Index (Nm/g) =	76.75
Tear Index (mN*m2/g) =	0.87
Stretch (%) =	6.21
Burst Index (KPa*m2/g) =	109.07

Synthetic = 15%, No Latex

No.	**CD Wt.**	**B.W.**	**Tensile Load**	**Extension**	**Tear**	**Burst Wire**	**Felt**
1.00	5.20	125.94	8.83	4.38	27.30		
2.00	4.82	116.73	8.09	3.40	27.30	65.00	54.00
3.00	4.74	114.80	7.96	3.82	27.30	50.00	50.00
4.00	4.61	111.65	8.03	4.22	23.75	50.00	46.00
5.00	4.65	112.62	8.11	3.90	23.75	52.00	48.00
6.00	4.86	117.70	9.01	3.41	23.75	50.00	52.00
7.00	4.96	120.13	8.15	3.83	28.30	45.00	51.00
8.00	4.92	119.16	7.83	2.66	28.30	47.00	52.00
9.00	5.09	123.27	7.54	2.85	28.30	63.00	57.00
Average	**4.87**	**118.00**	**8.17**	**3.61**	**26.45**	**52.75**	**51.25**
Std. Dev.	**0.18**	**4.45**	**0.44**	**0.55**	**1.95**	**6.81**	**3.19**

Tensile Index (Nm/g) =	**45.28**
Tear Index (mn*m2/g) =	**2.20**
Stretch (%) =	**3.61**
Burst Index (KPA*m2/g) =	**52.00**

25.

Nylon = 15%, 20% SBR / 80% Water

					Tensile		Tear	Burst	
No.	**CD wt**	**Sat CD**	**P.U.**	**B.W.**	**Load**	**Extension**		**Wire**	**Felt**
1.00	5.03	5.59	12.00	121.82	8.56	4.12	36.50	64.00	55.00
2.00	5.26	5.78	10.50	127.39	9.50	4.14	36.50	78.00	74.00
3.00	4.52	4.99	11.10	109.47	8.74	4.38	32.30	54.00	60.00
4.00	5.29	5.77	9.60	128.12	9.70	4.37	32.30	82.00	69.00
5.00	5.48	5.99	9.90	132.72	8.17	3.47	41.00	78.00	74.00
6.00	4.85	5.20	7.80	117.46			41.00	60.00	63.00
7.00	5.16	5.58	8.80	124.97	9.33	4.26	31.00	67.00	59.00
8.00	5.19	5.74	11.40	125.70	9.42	4.25		80.00	73.00
9.00	4.97	5.38	8.70	120.37	8.58	4.01		58.00	57.00
Average	**5.08**	**5.56**	**9.98**	**123.11**	**9.00**	**4.13**	**35.80**	**69.00**	**64.89**
Std. Dev.	**0.27**	**0.30**	**1.31**	**6.44**	**0.52**	**0.27**	**3.83**	**10.04**	**7.23**

Tensile Index (Nm/g) =	**47.80**
Tear Index (mN*m2/g) =	**2.85**
Stretch (%) =	**4.13**
Burst Index (KPa*m2/g) =	**66.94**

26.

Nylon = 15%, 50% SBR / 50% water

No.	CD wt	Sat CD wt	P.U.	B.W.	Tensile Load	Extension	Tear	Burst Wire	Felt
1.00	4.79	5.24							
2.00	4.91	6.14	26.80	118.91	9.02	5.27	31.83	84.00	75.00
3.00	4.79	5.99	26.70	116.01	8.08	4.08	34.00	90.00	78.00
4.00	4.84	6.01	25.70	117.22	9.48	5.54	34.00	88.00	86.00
5.00	4.56	5.72	27.20	110.44	9.69	5.46	41.17		
6.00	5.07	6.40	28.00	122.79	9.80	5.50	41.17	87.00	85.00
7.00	5.40	6.74	26.50	130.78	11.21	5.62	41.17	78.00	96.00
8.00	5.32	6.53	24.40	128.84	9.94	4.19	39.17	103.00	100.00
9.00	5.31	6.46	23.00	128.60	9.85	6.09	39.17	84.00	90.00
Average	**5.00**	**6.14**	**26.04**	**121.70**	**9.63**	**5.22**	**37.71**	**87.71**	**87.14**
Std. Dev.	**0.27**	**0.44**	**1.52**	**6.80**	**0.83**	**0.66**	**3.58**	**7.19**	**8.36**

Tensile Index (Nm/g) = 51.75
Tear Index (mN*m2/g) = 3.04
Stretch (%) = 5.22
Burst Index (KPa*m2/g) = 87.43

NYLON = 15%, 80% SBR / 20% WATER

					Tensile		Tear	Burst	
No.	**Cd wt**	**Sat CD wt**	**P.U.**	**B.W.**	**Load**	**Extension**		**Wire**	**Felt**
1.00	5.04	7.54	53.00	122.06	9.82	10.65	36.50	90.00	98.00
2.00	5.09	7.59	52.40	123.27	12.02	15.22	36.50		
3.00	5.13	7.60	51.30	124.24	10.92	10.62	36.67	94.00	113.00
4.00	5.05	7.35	48.70	122.30	11.68	9.76	36.67		
5.00	4.79	7.15	52.50	116.01	13.91	9.10	35.67	155.00	115.00
6.00	4.51	6.64	50.30	109.23	11.04	11.10	35.67	100.00	107.00
7.00	5.38	8.01	52.20	130.30	10.36	12.89	36.67	75.00	100.00
8.00	4.72	7.04	52.50	114.31	10.11	7.18	36.67	102.00	99.00
9.00	4.76	7.01	50.40	115.28	9.86	8.09	31.00	112.00	96.00
Average	**4.94**	**7.33**	**51.48**	**119.67**	**11.08**	**10.51**	**35.78**	**104.00**	**104.00**
Std. Dev.	**0.25**	**0.39**	**1.34**	**6.05**	**1.24**	**2.30**	**1.73**	**23.37**	**7.09**

Tensile Index (Nm/g) =	**60.53**
Tear Index (mN*m2/g) =	**2.93**
Stretch (%) =	**10.51**
Burst Index (KPa*m2/g) =	**104.00**

NYLON = 30%, NO LATEX

No.	CD wt	Sat CD wt	P.U.	B.W.	Tensile Load	Extension	Tear	Burst Wire	Felt
1.00	4.96			120.13	4.53	8.27	28.25		
2.00	5.20			125.94	4.41	7.63	28.25	52.00	78.00
3.00	5.17			125.21	5.02	7.92	17.63		55.00
4.00	4.49			108.74	4.49	7.76	17.63	45.00	48.00
5.00	5.20			125.94	5.97	3.98	24.63	54.00	53.00
6.00	5.16			124.97	4.66	2.06	24.63	47.00	51.00
7.00	4.83			116.98	4.31	6.81	29.75	51.00	50.00
8.00	4.48			108.50	4.12	9.05	29.75	44.00	48.00
9.00	4.97			120.37	4.73	6.49	29.75	56.00	64.00
Average	**4.94**			**119.64**	**4.69**	**6.66**	**25.59**	**49.86**	**55.88**
Std. Dev.	**0.27**			**6.58**	**0.51**	**2.12**	**4.65**	**4.26**	**9.66**

Tensile Index (Nm/g) =	**25.65**
Tear Index (mN*m2/g) =	**2.10**
Stretch (%) =	**6.66**
Burst Index (KPa*m2/g) =	**52.87**

NYLON = 30%, 20% SBR / 80% WATER

					Tensile		Tear	Burst	
No.	**CD wt**	**SAT CD**	**P.U.**	**B.W.**	**Load**	**Extension**		**Wire**	**Felt**
1.00	5.42	6.12	14.00	131.27	4.42	3.05	46.25	55.00	54.00
2.00	4.54	5.13	14.00	109.95	5.01	10.75	34.33	52.00	48.00
3.00	4.58	5.23	15.20	110.92	4.66	10.82	35.67	54.00	45.00
4.00	4.82	5.49	14.70	116.73	4.32	10.42	46.33	50.00	50.00
5.00	4.51	5.22	16.70	109.32	4.54	15.42	39.67	85.00	87.00
6.00	5.43	6.16	14.30	131.51	6.79	11.13	59.00	75.00	55.00
7.00	4.65	5.34	15.80	112.62	5.72	11.26	55.00		
8.00	4.73	5.40	15.20	114.55	5.80	10.29	41.67	54.00	49.00
9.00	5.02	5.71	15.80	121.58	5.27	10.84	48.25	76.00	67.00
Average	**4.86**	**5.53**	**15.08**	**117.61**	**5.17**	**10.44**	**45.13**	**62.63**	**56.88**
Std. Dev.	**0.34**	**0.36**	**0.87**	**8.18**	**0.77**	**3.00**	**7.82**	**12.81**	**12.99**

Tensile Index (Nm/g) =	**28.74**
Tear Index (mN*m2/g) =	**3.76**
Stretch (%) =	**10.44**
Burst Index (KPa*m2/g) =	**59.75**

30.

NYLON = 30%, 50% SBR / 50% WATER

No.	CD wt	SAT CD	P.U.	B.W.	Tensile Load	Extension	Tear	Burst Wire	Felt
1.00	5.07	5.63		122.79					
2.00	5.15	6.52	28.30	124.73	7.30	17.21	47.00	86.00	92.00
3.00	4.90	6.63	37.70	118.67	6.36	17.37	54.33	97.00	85.00
4.00	4.51	6.01	35.40	109.23	6.73	15.99	51.50	90.00	60.00
5.00	4.54	5.99	34.20	109.95	7.59	16.38	49.33	69.00	94.00
6.00	4.88	6.59	37.50	118.19	6.02	14.53	49.50	50.00	93.00
7.00	5.41	7.07	32.70	131.02	9.15	16.17	60.00	76.00	107.00
8.00	5.01	6.29	27.40	121.34	8.03	17.09	54.50	94.00	82.00
9.00	4.83	6.28	31.90	116.98	6.37	15.94	48.67	73.00	79.00
Average	**4.92**	**6.33**	**33.14**	**119.21**	**7.19**	**16.34**	**51.85**	**79.38**	**86.50**
Std. Dev.	**0.27**	**0.40**	**3.61**	**6.49**	**0.98**	**0.86**	**3.96**	**14.59**	**12.89**

Tensile Index (Nm/g) = 39.46
Tear Index (mN*m2/g) = 4.27
Stretch (%) = 16.34
Burst Index (KPa*m2/g) = 82.94

NYLON = 30%, 80% SBR / 20% Water

					Tensile		Tear	Burst	
Run No.	**CD wt**	**SAT CD**	**P.U.**	**B.W.**	**Load**	**Extension**		**Wire**	**Felt**
1.00	4.57	6.92	55.00	110.68	7.31	15.50	39.33	123.00	72.00
2.00	5.41	8.54	61.70	131.02	10.76	24.01	70.67	126.00	110.00
3.00	5.38	8.20	56.00	130.30	8.46	20.36	72.00	104.00	160.00
4.00	4.92	7.64	59.00	119.16	6.93	18.56	51.33	72.00	100.00
5.00	4.63	7.19	58.90	112.13	6.08	14.45	44.67	119.00	138.00
6.00	4.58	7.10	58.80	110.92	6.24	19.41	52.33	138.00	94.00
7.00	4.57	6.98	56.40	110.68	7.10	15.94	50.33		
8.00	5.28	8.01	55.10	127.88	7.89	19.06	59.00	122.00	117.00
9.00	4.72	7.28	58.00	114.31	6.99	14.56	51.67	105.00	108.00
Average	**4.90**	**7.54**	**57.66**	**118.56**	**7.53**	**17.98**	**54.59**	**113.63**	**112.38**
St. Dev.	**0.34**	**0.55**	**2.08**	**8.31**	**1.34**	**2.98**	**10.30**	**18.82**	**25.23**

Tensile Index (Nm/g) =	**41.52**
Stretch (%) =	**17.98**
Tear Index (mN*m2/g) =	**4.52**
Burst Index (KPa*m2/g) =	**113.00**