Influence of specific energy on the properties of hydroentangled nonwoven fabrics

Timothy J. Connolly and Laurent R. Parent

ABSTRACT: There is limited information concerning hydraulic entanglement in web processing and the end properties of the resulting fabrics. Accordingly, this paper addresses such common processing variables as specific energy input and basis weight as well as different energy ratios for the first side of the web to the total energy input. It compares carded and cross lapped webs and discusses results of strength, stiffness, thickness, wash durability, and fiber loss. There is a comparison of results to conventional woven and knit fabrics.

KEYWORDS: Basis weight, elongation, energy, fiber entanglement, nonwovens, process variables, stiffness, tear, tensile properties.

Nonwoven producers consider information regarding processing highly proprietary. As a result, there is little published information on the individual and interactive effects of hydraulic energy requirements on the physical properties and performance of hydroentangled fabric. Our work expands this body of knowledge with a special emphasis on the influence of specific energy on the properties of hydroentangled nonwoven fabrics.[1] To accomplish this there were consolidation trials on a laboratory pilot line and fabric testing and analysis in a physical testing laboratory.

A survey of current literature indicates that there is no documentation for the effect of specific energy use and specific energy ratio for the manufacture of hydroentangled fabrics. The objectives of our work were therefore as follows:

- Evaluate the interactive effects of hydraulic energy, specific energy ratio, fiber web forming method, and fiber web basis weight on hydroentangled nonwoven fabric properties and performance
- Determine the possibility of identifying an effective specific energy ratio
- Determine the amount of fiber attrition or weight loss associated with a specific energy condition
- Test conventional woven and knit fabrics to determine how physical properties such as tensile and burst strength compare to the properties of hydroentangled nonwovens.

The results of this work cover a broad range of product properties presented with statistical techniques. The results form a basis for product engineering and a guide for further study.

Specific energy

Specific energy is the energy used per kilogram of web which is treated at the orifice plate producing the water jets for hydroentangling. It is a function of the number of entangling manifolds and the pressure of treating the web. It does not include air movement energy for water evacuation or system losses and inefficiencies. The pressures used to process webs in this study ranged from 21 bar to 104 bar.

Specific energy is an independent variable which significantly affects fabric properties and performance. The specific energy ratio is the hydraulic energy delivered to the first side of the web divided by the total energy delivered. There may be a change in specific energy to provide an improvement in process economics or to prepare a wide range of products suitable for specific uses.

Connolly is a process engineer at Veratec, P. O. Box 20, Lewisburg, PA 17837, and Parent is manager, process engineering at Honeycomb Systems, Inc., P. O. Box 502, Biddeford, ME 04005.

[1]Connolly, T. J., M.S. thesis, The Institute of Textile Technology, Charlottesville, 1991.

I. Listing of tests for fabrics

- Basis weight, ASTM D 3776, Option A
- Thickness, ASTM D 1977
- Breaking load and elongation, ASTM D 1682
- Bursting strength, ASTM 3786
- Elmendorf tear strength, ASTM D 1424-83
- Fabric stiffness, ASTM D 1388, Option A
- Determination of fiber loss
- Wash durability

II. Factorial design

		C1			C2		
		B1	*B2*	*B3*	*B1*	*B2*	*B3*
E1	R1	X	X	X	X	X	X
	R2	X	X	X	X	X	X
	R3	X	X	X	X	X	X
E2	R1	X	X	X	X	X	X
	R2	X	X	X	X	X	X
	R3	X	X	X	X	X	X
E3	R1	X	X	X	X	X	X
	R2	X	X	X	X	X	X
	R3	X	X	X	X	X	X

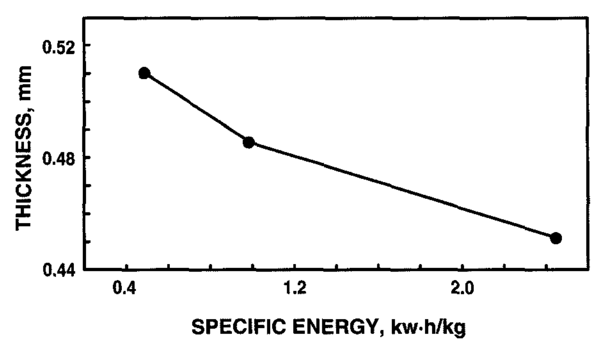
E: Specific energy, kW·h/kg
- E1: Low energy (0.49)
- E2: Medium energy (0.98)
- E3: High energy (2.46)

R: Specific energy ratio
- R1: 30%
- R2: 50%
- R3: 70%

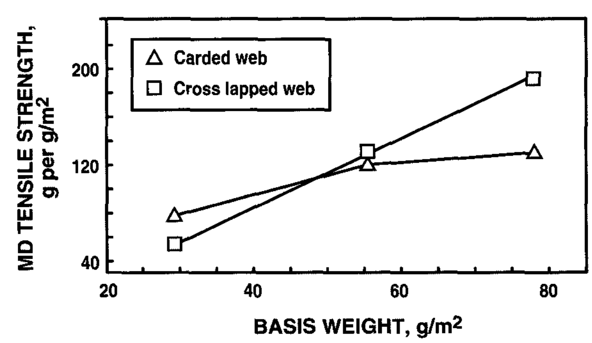
B: Basis weight, g/m²
- B1: 30
- B2: 60
- B3: 90

C: Forming method
- C1: Carded web
- C2: Cross lapped web

1. The effect of specific energy use on fabric thickness



2. The effect of web type and basis weight on MD tensile strength



It is a common practice to hydroentangle webs on the first side using low hydraulic pressures on a fine, wire mesh substrate. Sometimes there is a second-side entangling treatment. This would maximize strength, eliminate two-sidedness, minimize fiber loss associated with a one-side treatment, or create apertures or patterns. Two-sidedness means one side is entangled and the other is "fuzzy". Passing a fabric through the entangling zone twice so that the side against the forming screen on the first pass becomes the water jet manifold side on the second pass provides two-side entanglement.

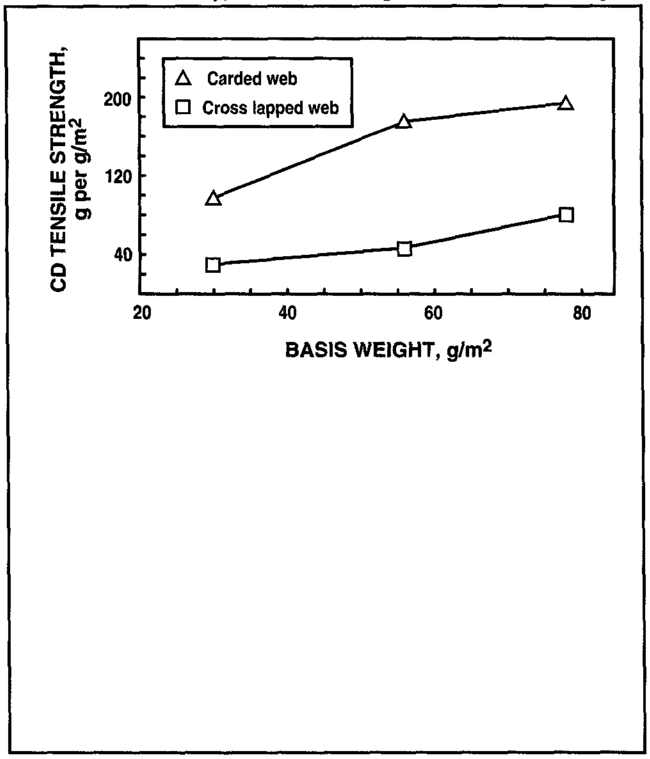
Experimental procedures

Selection of the experimental procedures permitted evaluation of the major processing variables for hydraulic web entanglement in relation to fabric characteristics. There was variation of specific energy levels, ratio of specific energy use, method of web forming, and web basis weight to produce 54 different fabrics. Performing a statistical analysis of variance on the test data allowed determination of the effects of these processing variables on fabric properties and performance.

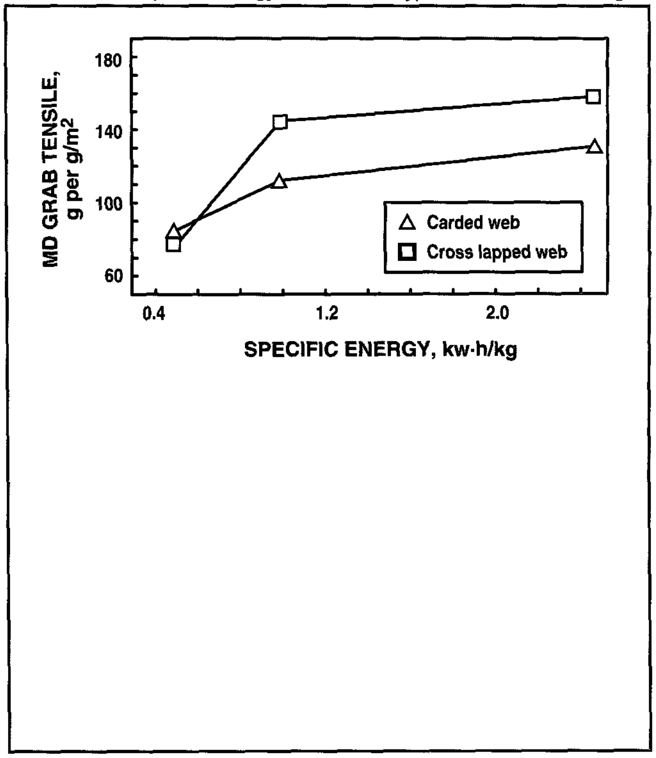
Use of a polyester and rayon blend containing fibers of similar deniers and staple lengths reduced the test variability.

The work produced a web consisting of a polyester and rayon blend using equal parts of each at specified

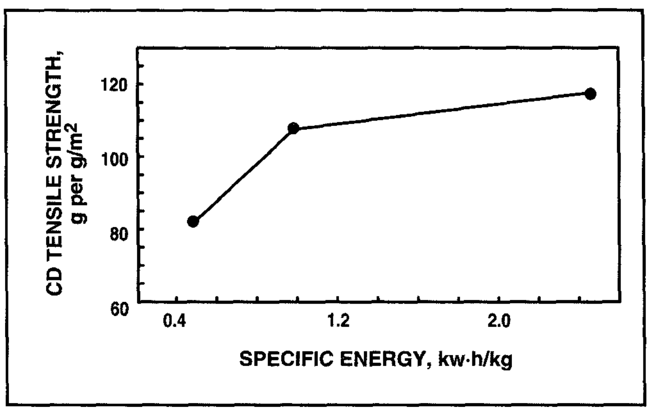
3. The effects of web type and basis weight on CD tensile strength



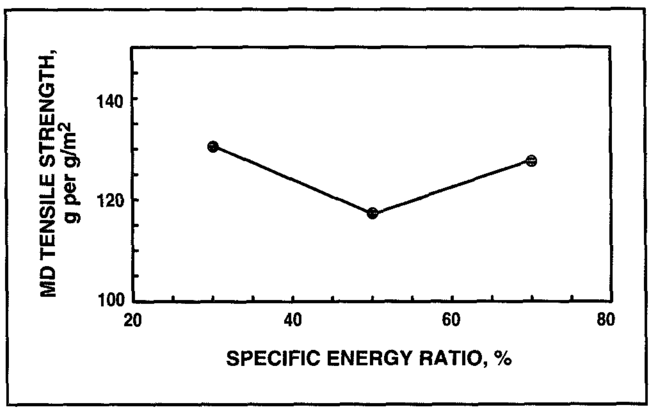
4. The effect of specific energy use and web type on MD tensile strength.



5. The effect of specific energy use on CD tensile strength



6. The effect of specific energy ratio on MD tensile strength



weights for each sample condition. We opened, weighed, and mixed the polyester and rayon fibers to form carded and cross lapped webs. We fed fiber to a master card to form the carded webs with web weights of 30, 60, and 90 g/m^2. In addition we used a commercial unit to cross lap the carded web.

A high pressure, rotary, hydroentangling system consolidated the carded and cross lapped webs. Hydroentangled, cross lapped webs provide fabrics with comparable physical properties in both the machine and cross-machine directions. This simulates a woven–like fabric. Carded precursor webs simulate knit–like fabrics with fibers oriented primarily in the machine direction (MD) to yield fabrics that are highly extensible when stretched in the cross direction (CD).

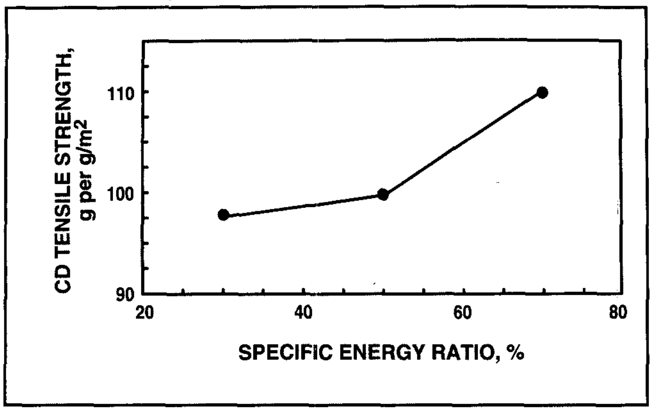
There were entanglement tests using carded and cross lapped webs of three basis weights. We made fabrics using three specific energy levels. The experiment used specific energies of 0.49, 0.98, and 2.46 kW·h/kg.

Specific energy input is a function of the number of entangling manifolds and the web treating pressure as well as speed and basis weight.

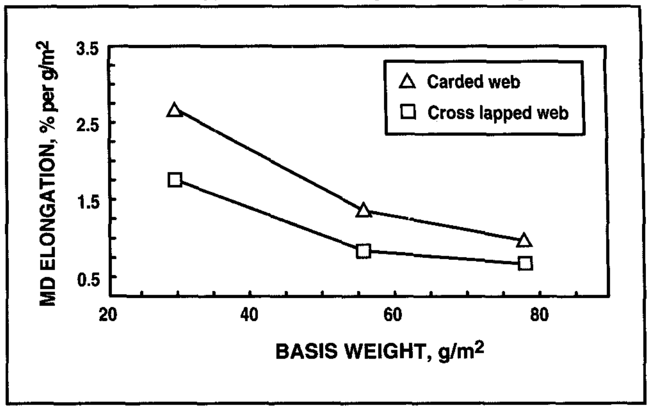
Incorporating three levels of specific energy ratio within each level of specific energy gave fabric suitable for testing. The intermediate ratio of specific energy use was 50%. A low specific energy ratio of 30% and a high ratio of 70% were the extreme values.

Table I shows the tests performed on the fabrics from each combination of

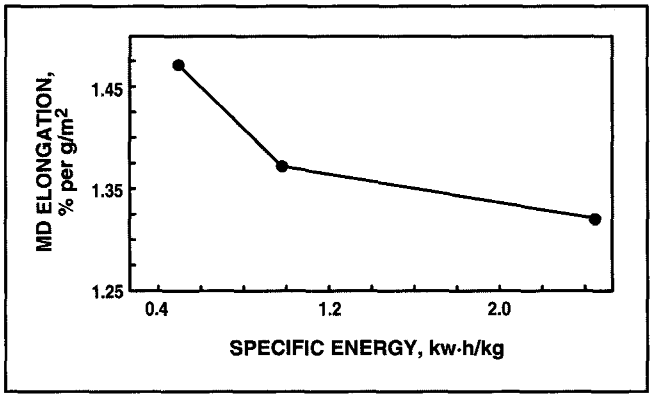
7. The effect of specific energy ratio on CD tensile strength



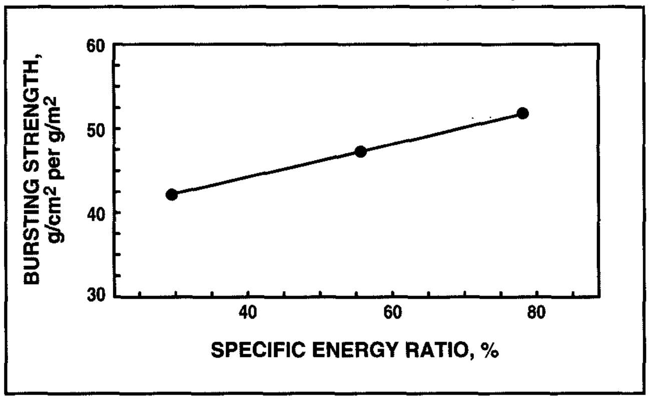
8. The effect of web type and basis weight on MD elongation



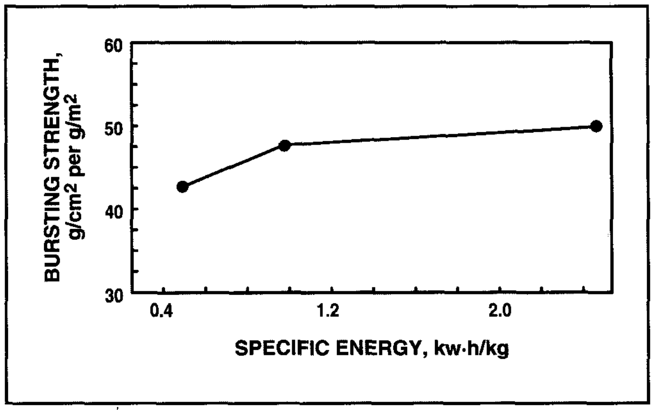
9. The effect of specific energy use on MD elongation



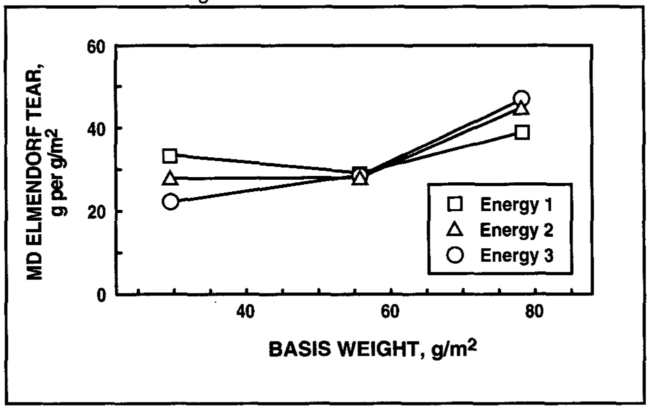
10. The effect of basis weight on fabric bursting strength



11. The effect of specific energy use on fabric bursting strength



12. The effect of specific energy use and basis weight on MD Elmendorf tear strength



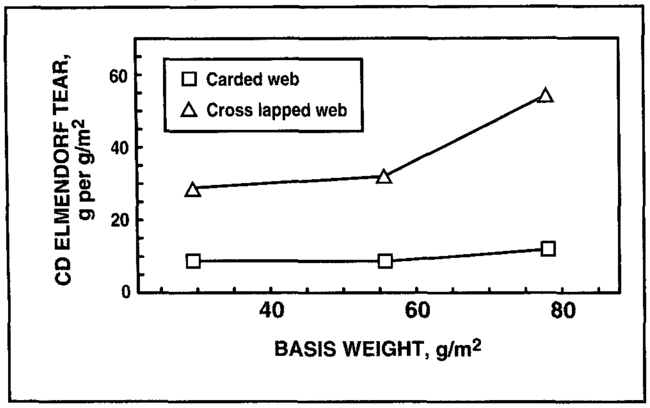
processing variables. **Table II** provides the factorial design selected to analyze the effects of specific energy, ratio of specific energy use, web forming method, and fiber basis weight on fabric physical properties and performance.

Analysis of variance calculations on each set of test data provided a determination of those processing variables that had a significant effect at the 95% confidence level. A comparison of means determined which levels of each variable had a significant effect at the 95% level.

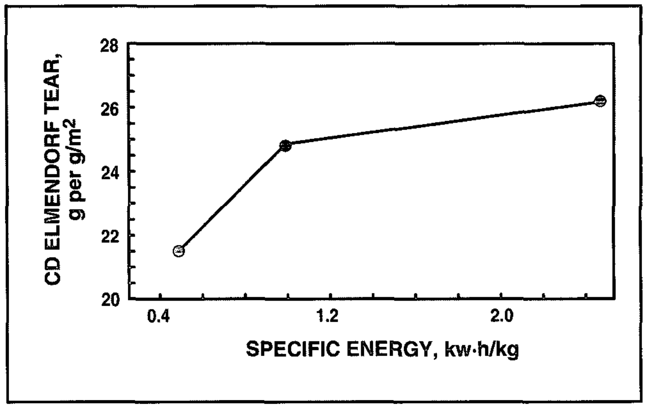
Results

The benefit of a factorial design is maintaining accuracy to assess the shape of the operating surface while using only a minimum number of data points for multiple independent variables. Improved accuracy will result with the use of every data point for the calculation of each parameter. Each result, therefore, uses the mean of all the data points for the factor of interest. **Figure 1** is an example, since

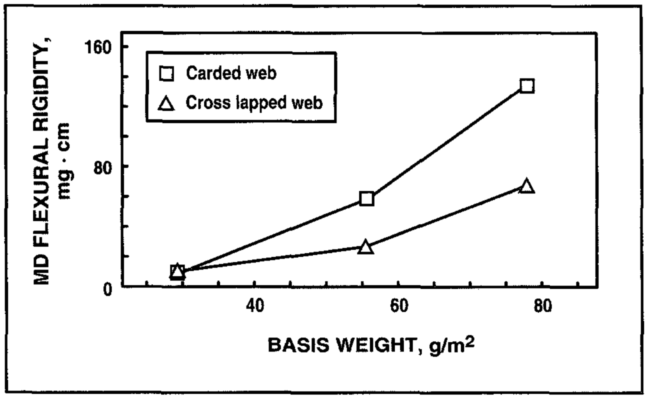
13. The effect of web type and basis weight on CD Elmendorf tear strength



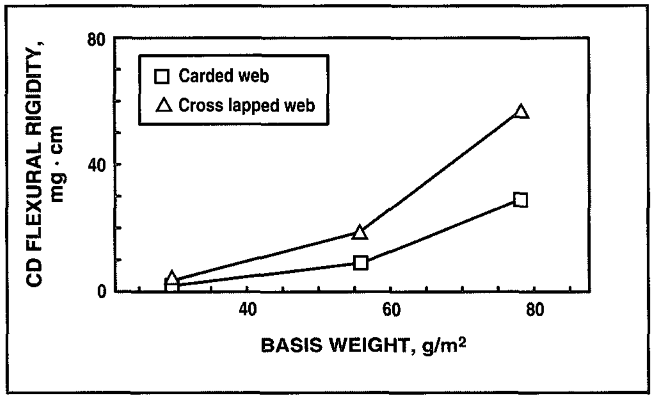
14. The effect of specific energy use on CD Elmendorf tear strength



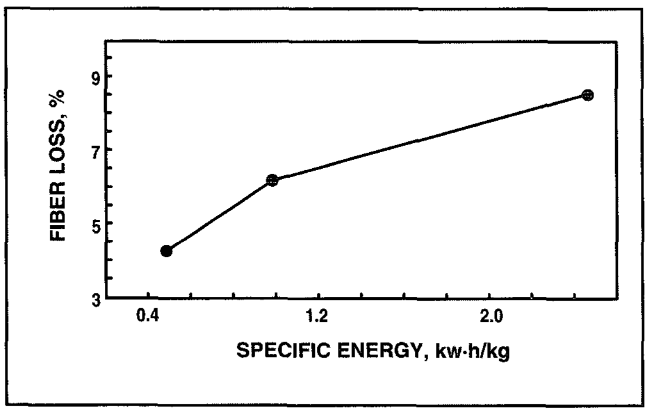
15. The effect of basis weight and web type on MD flexural rigidity



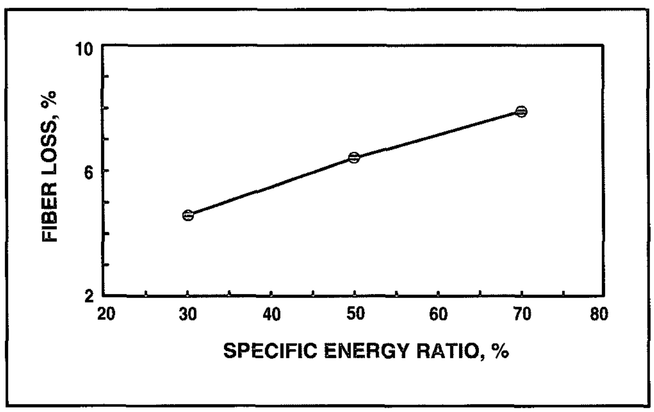
16. The effect of basis weight and web type on CD flexural rigidity



17. The effect of specific energy use on percentage fiber loss



18. The effect of specific energy ratio on percentage fiber loss



III. Comparative fabrics

Poplin fabric, 147 g/m², 65% polyester with 35% combed cotton
Sheeting fabric, 115 g/m², 100% cotton
Handkerchief linen, 117 g/m², 50% polyester with 50% rayon
Interlock knit, 205 g/m², 100% cotton
Jersey knit, 182 g/m², 50% polyester with 50% cotton

it uses a thickness calculation from the average of the values of all basis weights, all energy ratios, and both web types for each specific energy level.

Basis weight

Grab tensile samples allowed calculation of final basis weights. Fiber loss and web processing caused draw down, which yielded average basis weights below target levels. The averages were 29.5, 55.8, and 78.2 g/m^2 for target values of 30, 60, and 90 g/m^2, respectively. Carded webs were about 5% lighter than cross lapped ones.

Thickness

Fabric thickness was a function of web type, basis weight, and specific energy use. Final fabrics from carded precursor webs were thicker than fabrics developed from cross lapped webs. As expected, thickness increased with basis weight. Average thicknesses for each basis weight were 0.33, 0.50, and 0.62 mm. For all webs combined, Fig. 1 shows a decrease in average thickness with increasing specific energy, with a significant decrease from 0.98 to 2.46 kW·h/kg.

Tensile strength

Analysis of variance shows that basis weight, web type, specific energy ratio, and specific energy significantly affect both MD and CD tensile strength at the 95% confidence level. All tensile strength data represents a normalized approximation of fabric strength free from the effects of basis weight fluctuations.

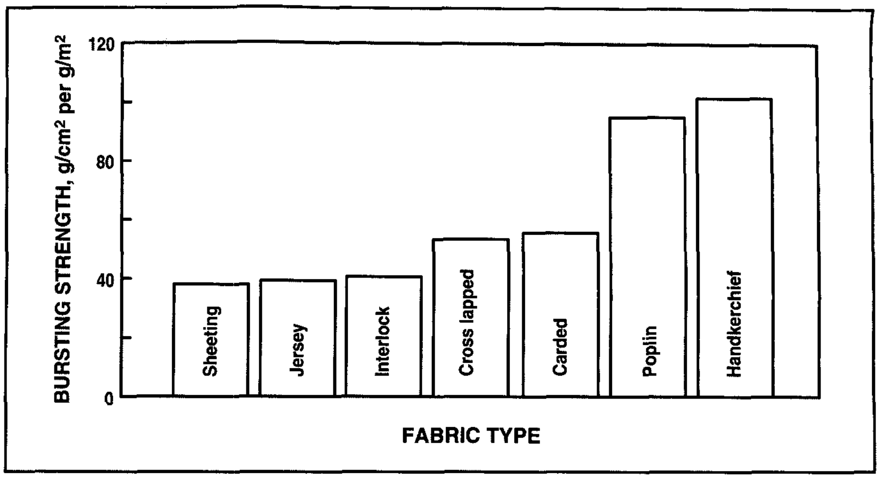
Figures 2 and 3 show that heavier fabrics result in greater strength in both MD and CD. One would expect this trend. However, significant increases in tensile strength occur up to the heaviest fabric even when normalized for basis weight. This suggests a high degree of entanglement in the *z* direction when sufficient fiber is available.

The variations of tensile strength with specific energy agree with results reported in other literature.[2] As **Figs. 4 and 5** indicate, strength does increase, but the effect diminished above 0.98 kW·h/kg.

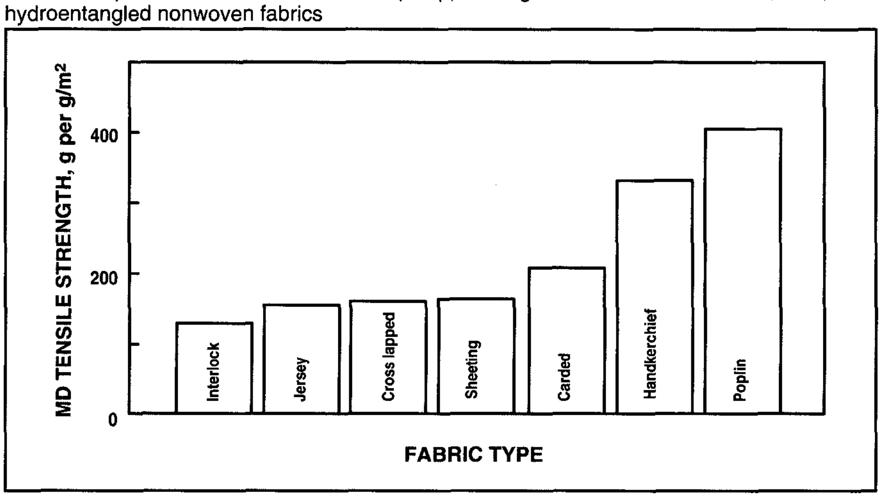
Figure 6 clearly shows the effect of specific energy ratio. The least strength develops when the energy is even over both sides of the web. It is at

[2]Randall, K. R., Hydro-entanglement Technology for Wet Laid Applications, Miller Freeman Publications, San Francisco, 1988.

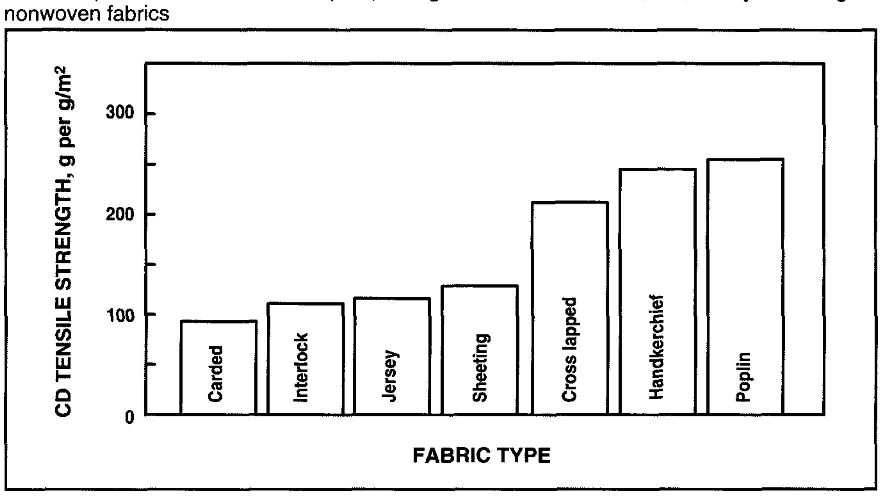
19. A comparison of normalized bursting strengths for selected woven, knit, and hydroentangled nonwoven fabrics



20. A comparison of normalized MD (warp) strengths for selected woven, knit, and hydroentangled nonwoven fabrics



21. A comparison of normalized CD (weft) strengths for selected woven, knit, and hydroentangled nonwoven fabrics



maximum at the lowest energy ratio. When comparing 30% and 70% ratios, the difference in strength is insignificant. **Figure 7** shows that the lowest energy ratio yields the minimum CD tensile strength.

Elongation

Basis weight, web type, and specific energy affect elongation. Energy ratio does not have an effect. MD elongation decreases at higher basis weights. **Figure 8** illustrates this. Cross lapped webs had more elongation than carded webs. **Figure 9** shows that increased specific energy results in less elongation. Each significant independent variable exhibits a consistent inverse relationship between strength and elongation. CD elongation results follow the same pattern as MD elongation with the relative magnitudes swapped for carded and cross lapped webs.

Bursting strength

Basis weight and specific energy use significantly influenced bursting strength at the 95% confidence level. **Figures 10 and 11** show that both variables had the same effect on bursting strength as on tensile strength.

Tear strength

Testing entangled cross lapped webs provided MD Elmendorf tear data. Poor MD tears were typical for carded webs because fibers in carded webs are predominantly oriented in the MD. **Figure 12** illustrates the interactive effect of specific energy use and basis weight on MD Elmendorf tear data. The influence of specific energy alone was not statistically significant.

The Elmendorf tear data used both web types in the CD. **Figure 13** shows the influence of basis weight for both web types. Cross lapped webs exhibited a higher tear strength than carded webs and were influenced more by increased basis weight. **Figure 14** shows that the CD tear strength relationship with specific energy followed the same pattern as other strength tests.

Flexural rigidity

Basis weight and web type in both the MD and CD affected flexural rigidity, a measure of fabric stiffness. Additionally, the specific energy use influenced CD. **Figure 15** shows flexural rigidity and the interactive effect of basis weight and web type for MD. **Figure 16** shows the same for CD. A greater number of fibers per unit area and a greater number of fibers in the test direction both contribute to greater stiffness. A significant increase in CD flexural rigidity occurs between 0.46 and 0.98 kW·h/kg. Above 0.98 kW·h/kg, however, there is no significant increase.

Fiber loss

Of the independent variables considered in this work, only basis weight, specific energy use, and specific energy ratio affected percentage fiber loss at the 95% confidence level. Weighing the rolls of web before and after hydroentanglement allowed determination of fiber loss.

The low-basis-weight material averaged about 9% fiber loss. Fiber loss leveled off at a little over 5% for the medium and high basis weights.

Fiber loss is a continuously increasing function of specific energy input. **Figure 17** shows that increases in percentage fiber loss were significant.

Figure 18 shows that specific energy ratio has the greatest effect on the percentage of fiber loss. Clearly a light treatment on the first side is preferable. The combination of low energy use on the first side with high energy use on the other side seems to "lock in" more fibers. With high energy on the first side, there are more fibers blown through the carrying substrate.

Wash durability

To compare wash durability results among fabrics produced at different energy levels, we washed samples in synthetic laundering bags. All 30- and 60-g/m² carded fabrics failed the first wash cycle. The 90-g/m² carded fabrics survived only one wash cycle. Fabric breaking apart or severe pilling were indications of failure.

The low energy, 60–90-g/m² cross lapped fabrics survived one wash cycle. The medium energy, 60–90-g/m² cross lapped fabrics survived two wash cycles. The high energy, cross lapped fabrics survived three wash cycles. After three cycles, however, there was severe pilling and disentanglement.

Comparison to woven and knit fabrics

The hydroentangled nonwovens of this study are relatively light in weight compared to conventional woven and knit fabrics. **Table III** shows the fabrics used for comparative purposes. **Figure 19** illustrates a normalized comparison of bursting strength. **Figures 20 and 21** illustrate a normalized comparison of MD (warp) and CD (filling) tensile strengths. The hydroentangled webs were 1.5–2 times thicker than the conventional woven and knit fabrics when normalized by basis weight.

Conclusion

This work has confirmed conclusions from previous studies concerning the relationship between fabric strengths and specific energy levels. Higher energy levels result in stronger fabrics up to a certain point. Additionally, we have shown that shifting the balance of energy input to the second side (low specific energy ratio) can decrease fiber loss significantly. The benefits of different energy ratios on strength properties are not so clear. There is the suggestion that the 50% ratio might not be ideal. Further studies with a more limited set of independent variables and a larger sampling might show a clearer strength benefit for higher or lower energy ratios.

A comparison to conventional woven and knit fabrics indicates that simple carded and cross lapped hydroentangled fabrics can be comparable in strength but not in wash durability. **TJ**

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