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Energy transfer during the hydroentanglement of fibres

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ABSTRACT

The hydroentanglement of fibres is achieved by the energy of the high-velocity waterjets. This method is highly energy intensive and costly, hence the attempt to study the energy transfer during the process. Generally, the amount of energy used, and the resultant degree of fibre entanglement, determines the tensile strength of the nonwoven fabric as a consequence of the inter-fibre friction. Here, the relationship between hydroentangling energy from the waterjets and the changes it brings about in the nonwoven fabric strength were studied. In the study, the energies of the waterjets transferred to every fabric sample as a function of the waterjet pressure, machine speed, machine efficiency and the web area weight were quantified, and the resultant fabric tensile strengths were compared. The nonwovens were produced from viscose and PLA fibres using different energy profiles; the objective being to identify the most energy-efficient. The light PLA nonwoven fabrics, which were less than 150 g/m^2, showed a relatively higher change in the cross-machine direction strength than the corresponding viscose nonwoven fabrics.

INTRODUCTION

The hydroentanglement process is a technique for manufacturing nonwovens by means of high-velocity waterjets which entangle the fibres to produce a nonwoven. The kinetic energy of the waterjets is transferred to the fibres on impact, thus improving the integrity of the structure. The resultant hydroentangled nonwoven has tensile strength largely reflecting the degree of fibre entanglement within the structure. A high degree of fibre entanglement increases the inter-fibre friction and the tensile strength.[1,2] In this study, the relationship between the hydroentangling energy from the waterjets and the changes it brings about to the nonwoven fabric strength were studied. The hydroentanglement energy is a function of the waterjet pressure, machine speed and the fabric weight. Thus, by studying different energy profiles from a combination of different levels of parameters, and the resultant fabric tensile strengths achieved, the most efficient combination was identified. The initial assumption was that the fibre webs had negligible tensile strength, and the resultant fabric strength was directly related to the energy transferred from the waterjets. Therefore, by quantifying the different waterjet energies transferred to every fabric sample as a function of the waterjet pressure, machine speed, machine efficiency and the web area weight, an objective comparison was made.

METHODOLOGY

The hydroentangled nonwovens were produced from viscose and polylactic fibres according to the 3x3 Box-Behnken experimental design. The processing variables, namely, average fabric weight, machine speed and waterjet pressure were varied at (150, 250, 350 g/m2), (5, 10, 15 m/min) and (100, 150, 200 bars), respectively.

RESULTS AND DISCUSSION

The equation used to calculate the hydroentanglement energy is as follows:

$$K = \frac{1}{bmV_b} \cdot \frac{C_d \pi \sqrt{2}}{4\sqrt{\rho_w}} \cdot \sum_{i=1}^{N} n_i l_i d_i^2 P_i^{3/2} \qquad [1]$$

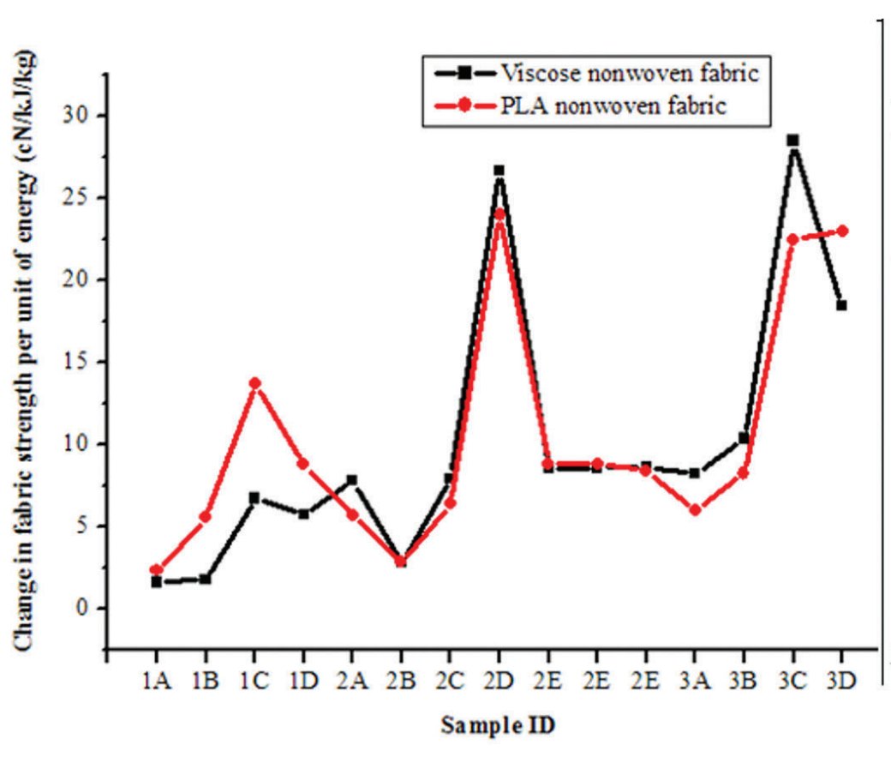
Where K is the specific energy consumed by a unit mass of the web (J/kg), b is the width of the web, m is the area density of the web (kg/m^2), V_b is the conveyor belt velocity (m/min), P_i is the waterjet pressure at the ith injector (bars), C_d is the nozzle measured discharge coefficient, ρ_w is the water density = 1 000 kg/m^3, and $n_i{\cdot}l_i$ is the number of waterjets on the ith injector.[1]

Identifying the most efficient energy profile to lower the production costs in hydroentanglement of nonwovens.

The calculated hydroentanglement energy was then related to the change in fabric strength, as summarised or defined by the following equation:

$$\text{Change in tensile strength per unit of energy supplied} = \frac{\text{Fabric tensile strength (cN)}}{\text{Specific energy, K (kJ/kg)}} \qquad [2]$$

The results from Equation 2 were used to plot **Figure 1**, which shows the change in the fabric tensile strength in the machine-direction per unit of hydroentanglement energy. The most efficient combination of parameters, or energy profiles, produces the highest degree of fibre entanglement, or change in tensile strength.



KEY

Sample identity	Processing variables		
	Average fabric area weight (g/m^2)	Machine speed (m/min)	Waterjet pressure (bars)
1A	150	5	150
1B	150	10	200
1C	150	10	100
1D	150	15	150
2A	250	10	100
2B	250	10	200
2C	250	15	200
2D	250	15	100
2E	250	10	150 **(3 Repeats)**
3A	350	5	150
3B	350	10	200
3C	350	10	100
3D	350	15	150

Figure 1: Change in viscose and PLA nonwoven fabric tensile strength per unit of hydroentangling energy used

In **Figure 1**, the light PLA nonwoven fabrics (1A, 1B, 1C and 1D) showed a relatively higher change in the CD strength than the corresponding viscose nonwoven fabrics. Thus, light PLA nonwovens utilised the hydroentanglement energy more efficiently to consolidate the fibres and increase their tensile strength than the corresponding viscose nonwovens. The trend in the utilisation of energy by both viscose and PLA fabrics were very similar for most samples, with peaks and troughs occurring in similar areas. Heavier viscose nonwovens were more energy-efficient than viscose nonwovens.

It is noteworthy that none of the peaks occurred at the two highest waterjet pressures, as may have been expected. This is an important finding, since employing high waterjet pressures is the single largest contributor to the high cost of the hydroentanglement process. If the waterjet pressure is above the optimum, slow machine speeds render the process inefficient. High waterjet pressures and high energy levels do not always translate to high efficient energy transfer.

CONCLUSION

Although more energy can be transferred at low machine speeds, there was no corresponding substantial change in fabric tensile strength. Therefore, high machine speeds at high waterjet pressures would not necessarily compromise the nonwoven fabric tensile strength, although the energy transferred is low. Instead productivity would be increased. Also, it was possible to use lower waterjet pressures, and therefore energy, without a reduction in fabric tensile strength.

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