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Studies on the Moisture Management Characteristics of Spunlace Nonwoven Fabric

Študij lastnosti prenosa vlage skozi vlaknovine, utrjene z vodnim curkom

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Abstract

Liquid moisture transfer, sweat absorbency and sweat drying in clothing have a significant influence on the wearer's perception. Moisture management is one of the key performance criteria in determining the comfort level of fabric. It is thus important to study the moisture management characteristics of spunlace nonwoven fabric to investigate the possibility of its use in apparel. In the present study, spunlace nonwoven fabrics were produced by varying waterjet pressure, delivery speed, web mass and web composition. The effect of different parameters on various properties of the moisture management tester was studied using a response surface methodology with backward elimination. The statistical analysis showed that web composition affected all parameters of the moisture management tester. Waterjet pressure and web mass do not have a significant effect on wetting time (top), absorption rate (bottom) and one-way transport capability. The effect of delivery speed was not found to be significant. The overall moisture management coefficient of all nonwoven fabrics studied was found to be very good. An increase in web mass resulted in a decrease in the overall moisture management coefficient value of nonwoven fabric, which can be halted by using higher waterjet pressure and through the proper selection of web composition. Nonwoven fabric with either 100% viscose or 50% polyester/50% viscose blended composition, with higher waterjet pressure and higher web mass, was found to be suitable for the apparel industry.

Keywords: moisture, overall moisture management coefficient, waterjet pressure, web mass

Izvleček

Prenos in absorpcija znoja ter sušenje znoja pomembno vplivajo na občutek nošenja oblačil. Odziv oblačil na vlago je eden ključnih dejavnikov vrednotenja udobnosti tekstilnega materiala. Zato je za oceno primernosti vlaknovin, utrjenih z zračnim curkom, za oblačila pomembno proučiti njihovo odzivanje na vlago. V tej študiji so bile izdelane vlaknovine, utrjene z različnimi pritiski vodnega curka, različnimi hitrostmi izdelave, z različnimi ploščinskimi masami in surovinsko sestavo. Z uporabo metodologije odzivnih površin in povratne eliminacije so bili proučeni različni vplivni parametri vlaknovin na izmerjene lastnosti prenosa vlage. Statistična analiza je pokazala, da surovinska sestava vpliva na vse parametre prenosa vlage. Tlak vodnega curka in ploščinska masa vlaknovine nista pomembno vplivala na njen čas omočenja (zgornje strani), hitrost absorpcije (na spodnji strani) in sposobnost odvajanja vlage. Tudi hitrost izdelave vlaknovine ni imela pomembnega vpliva. Ugotovljeno je bilo, da je bil skupni koeficient odzivanja na vlago pri vseh vlaknovinah zelo dober. Povečanje ploščinske mase je vplivalo na znižanje skupnega koeficienta odzivanja vlaknovine na vlago, kar pa je mogoče preprečiti z uporabo višjega pritiska vodnega curka in z ustrezno izbiro surovinske sestave vlaknovine. Ugotovljeno je bilo, da so vlaknovine iz 100-odstotnih viskoznih vlaken ali iz mešanice 50 % poliester/50 % viskoza ob uporabi višjega pritiska vodnega curka in večji ploščinski masi primerne za izdelavo oblačil.

Ključne besede: vlaga, skupni koeficient prenosa vlage, tlak vodnega curka, ploščinska masa

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1 Introduction

Moisture regulation is one of the key performance parameters in today's apparel industry. The microclimate between the skin and clothing should be thermally stable via moisture management, [1] and has a significant effect on the thermo-physiological comfort of the human body [2]. Moisture vapour transfer and liquid moisture transfer (sweat absorbency and sweat drying) in clothing plays an important role in the wearer's perception. Moisture management fabric should transfer sweat in vapour moisture form when the body is motionless and should allow liquid moisture to be drawn off to the outer surface to evaporate when the body is working [3]. The multidimensional moisture transport property of a fabric is generally referred to as moisture management characteristics [4]. Fibre-liquid interaction affects the moisture management of fabric [5]. Fibre-liquid interaction phenomena depend on the surface tension and pore diameter/porosity of a fabric [6–7]. Because the transfer of heat and moisture through fabric is vital for designing clothing for specific uses, [8] many theoretical and experimental studies have been conducted to understand the moisture transport phenomenon for both woven and knitted structures. Very few studies, [9–12] however, have discussed the moisture transport characteristics of nonwoven fabrics.

Nonwoven fabrics are engineered fabrics that today are used almost everywhere. Spunlace nonwoven fabric is the most promising technology for the production of fabric used extensively in the apparel industry, on account of its good handling and tensile properties. Its structure also offers good structural integrity and is comparable to other nonwoven products. Spunlacing (hydroentanglement) is a mechanical type of bonding that uses high-speed jets of water to strike a web, so that fibres knot about one another [13]. The physical characteristics of hydroentangled nonwoven fabrics, such as softness, flexible handling, high drape and bulk, conformability and high strength without binders and good delamination resistance, make it unique among all other types of nonwoven fabrics. Applications of this fabric include bacteria-proof clothing, wet wipes and as interlining fabric [14]. Recent research also suggests the application of spunlace nonwoven fabrics in fashion apparel [15-16]. Application in the apparel industry, however, requires the careful study of thermal and moisture transmission characteristics. Limited reports in this regard are available. Hajiani et al. [17] studied the absorbency behaviour of spunlace nonwoven fabrics produced at varying water jet pressures and different basic fabric weight. Increased jet pressure was reported to increase mass density, while water retention and permeability were reduced. Berkalp [18] studied the air permeability and porosity of spunlace nonwoven fabric, but did not discuss moisture transfer. He stated that the pore structure of nonwoven fabric affects various comfort properties, such as thermal conductivity and air permeability. The pores inside nonwoven fabrics are highly complex in terms of size, shape and capillary geometry [19]. Knowledge of pore size distribution is essential for understanding transport phenomena, particularly in a porous structure such as nonwoven fabric [20]. The absorption and spreading of fluid can be engineered by controlling the pore configurations of the substrate, [11, 21] while studies of the moisture and heat transfer characteristics of light nonwoven fabric have reported that a blend with hydrophobic fibre has a favourable effect on the drying behaviour of fabric. Ahmad et al. developed a hydroentangled fabric using comber noil and reported that waterjet pressure and conveyor speed (delivery speed) affect the moisture management properties of fabric [12].

The moisture transport characteristics of a fabric can be affected by any of the following parameters:

(i) the nature and quantity of each constituent fibre;
(ii) the structural parameters of fabric (which define the fluid flow passage geometry, i.e. pore size and the distribution thereof);
(iii) the mass and thickness of the material; and/or
(iv) structural or surface modification through mechanical or chemical treatment.

An attempt has been made in this study to investigate the effect of different material and process parameters of spunlace nonwoven fabric on the moisture management characteristics thereof.

2 Material and methods

2.1 Materials

Twenty-seven spunlaced nonwoven fabrics were produced from cross-laid carded web by varying water pressure, delivery rate, web composition and web mass, using a Box-Behnken experimental design. Viscose (38 mm, 1.4 dtex) and polyester (38 mm, 1.4 dtex) fibres were used in the study. Two fibres with significantly different moisture absorption characteristics

Table 1: Factors and the levels thereof for the Box-Behnken design

Material and process parameters	Level		
	–1	0	1
Waterjet pressure [bar] X_1	50	100	150
Delivery speed [m/min] X_2	1	3	5
Web mass [g] X_3	50	100	150
Web composition X_4	PET a)	50PET/50CV b)	CV c)

a) Hereinafter, the abbreviation PET is used for 100% PET. b) Hereinafter, the abbreviation 50PET/50CV is used for a 50% PET/50% viscose blend. c) Hereinafter, the abbreviation CV is used for 100% viscose.

Table 2: Physical parameters of nonwoven fabric samples [22]

Sample code	Waterjet pressure [bar] X_1	Delivery speed [m/min] X_2	Web mass [g] X_3	Web composition X_4	Fabric weight Mean/COV a) [g/m^2]/[%]	Fabric thickness Mean/COV [mm]/[%]	Mean pore diameter Mean/COV [µm]/[%]
1	50.00	1.00	100.00	50PET/50CV	98.5/6.23	1.64/8.44	74.320/5.84
2	150.00	1.00	100.00	50PET/50CV	97.2/5.29	1.00/7.64	43.980/8.57
3	50.00	5.00	100.00	50PET/50CV	99.1/8.25	1.60/7.94	75.900/9.55
4	150.00	5.00	100.00	50PET/50CV	147.6/6.87	1.08/6.66	44.840/6.5
5	100.00	3.00	50.00	PET	43.7/6.78	0.94/8.29	95.830/7.79
6	100.00	3.00	150.00	PET	148.2/5.69	1.20/7.13	75.270/6.27
7	100.00	3.00	50.00	CV	42.8/7.59	0.62/5.29	60.500/4.26
8	100.00	3.00	150.00	CV	145.7/6.63	1.12/4.92	38.500/4.52
9	100.00	3.00	100.00	50PET/50CV	96.7/8.91	0.90/8.27	53.530/7.22
10	50.00	3.00	100.00	PET	98.4/7.53	1.28/6.4	98.390/6.17
11	150.00	3.00	100.00	PET	96.2/9.39	1.20/7.88	62.920/8.51
12	50.00	3.00	100.00	CV	97.8/9.39	0.88/7.21	46.685/8.36
13	150.00	3.00	100.00	CV	96.3/7.27	0.79/5.89	36.063/5.96
14	100.00	1.00	50.00	50PET/50CV	48.9/6.31	0.85/8.24	58.780/7.47
15	100.00	5.00	50.00	50PET/50CV	48.5/5.49	0.89/9.22	49.160/6.58
16	100.00	1.00	150.00	50PET/50CV	146.4/7.62	1.22/6.91	27.160/4.84
17	100.00	5.00	150.00	50PET/50CV	147.0/8.57	1.30/5.37	27.960/8.43
18	100.00	3.00	100.00	50PET/50CV	98.3/9.22	1.10/6.84	50.290/7.25
19	50.00	3.00	50.00	50PET/50CV	49.1/7.94	1.30/6.57	69.960/7.65
20	150.00	3.00	50.00	50PET/50CV	48.3/5.47	0.86/8.87	48.180/6.88
21	50.00	3.00	150.00	50PET/50CV	148.7/8.97	2.64/7.39	69.460/7.71
22	150.00	3.00	150.00	50PET/50CV	146.9/6.23	1.16/7.10	19.340/8.17
23	100.00	1.00	100.00	PET	98.4/4.59	1.21/9.44	67.140/7.27
24	100.00	5.00	100.00	PET	98.9/9.49	1.32/6.98	65.520/6.93
25	100.00	1.00	100.00	CV	96.3/7.29	0.73/4.64	50.260/5.7
26	100.00	5.00	100.00	CV	96.8/7.34	0.84/5.43	28.310/5.55
27	100.00	3.00	100.00	50PET/50CV	97.8/8.11	0.95/4.26	59.570/7.56

a) Hereinafter, the abbreviation COV is used for coefficient of variation.

were chosen to study the transport behaviour of moisture through the structure, in particular when using a blend of the two fibres. The corresponding values of different levels of the above-mentioned factors are presented in Table 1.

The fibre/fibre blends were first opened and carded using a stationary flat card. A bimodal fibre orientation in the web was achieved using a cross-lapper. A pilot-scale hydroentangling machine was used to produce fabric as per the required setting based on the Box-Behnken design. The machine was set-up with the following values: orifice discharge coefficient = 0.7, orifice diameter = 0.127 mm, number of jets/m = 1600 and pre-wetting pressure = 50 bars. The nozzle type, nozzle geometry and all other parameters were kept same for all samples. Various physical parameters were measured using standard methods for all nonwoven fabrics that were produced according to the Box-Behnken design [22]. Mean fabric weight, mean fabric thickness and mean pore diameter is presented in Table 2.

2.2 Methods

The moisture management behaviour of the fabrics was accurately and objectively measured on an SDL-ATLAS M290 moisture management tester according to the AATCC Test Method 195 [23]. A 5 cm x 5 cm fabric specimen was used in the tester. A certain known volume of a predefined test solution was then put on the top surface of the fabric (i.e. the side of the fabric in contact with skin). The saline solution transferred in three directions after being placed on the top surface of the specimen. The aforementioned instrument was integrated with a computer via moisture management software that records changes in resistance due to the solution, which can conduct electricity. Changes in the electrical resistance of specimens were measured and recorded during the test. According to the AATCC Test Method 195–2012 [23], the indices are graded and converted from a value to a grade based on a five-grade scale. Table 3 presents the range of values converted into grades.

Table 3: Grading of different indices obtained from the moisture management tester [23, 24]

Index	Grade				
	1	2	3	4	5
Wetting time – top [s]	≥120	20–119	5–19	3–5	<3
	No wetting	Slow	Medium	Fast	Very fast
Wetting time – bottom [s]	≥120	20–119	5–19	3–5	<3
	No wetting	Slow	Medium	Fast	Very fast
Absorption rate – top [%/s]	0–10	10–30	30–50	50–100	>100
	Very Slow	Slow	Medium	Fast	Very fast
Absorption rate – bottom [%/s]	0–10	10–30	30–50	50–100	>100
	Very Slow	Slow	Medium	Fast	Very fast
Max. wetted radius – top [mm]	0–7	7–12	12–17	17–22	>22
	No wetting	Small	Medium	Fast	Very fast
Max. wetted radius – bottom [mm]	0–7	07–12	12–17	17–22	>22
	No wetting	Small	Medium	Fast	Very fast
Spreading speed – top [mm/sec]	0–1	1–2	2–3	3–4	>4
	Very Slow	Slow	Medium	Fast	Very fast
Spreading speed – bottom [mm/sec]	0–1	1–2	2–3	3–4	>4
	Very Slow	Slow	Medium	Fast	Very fast
One-way transport capability (OWTC)	<−50	−50–100	100–200	200–400	>400
	Very poor	Poor	Good	Very good	Excellent
Overall moisture management coefficient (OMMC)	0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	>0.8
	Very poor	Poor	Good	Very good	Excellent

Finally, the moisture management tester classified the tested fabric into seven categories according to their properties, as presented in Table 4 [24].
Before conducting the test, all fabric samples were first conditioned in a tropical atmosphere of 27 °C ± 2 °C and 65% ± 2% relative humidity. For each sample of the Box-Behnken design, fifteen samples were tested to minimise the coefficient of variation (%). Minitab 17 software was used for statistical analysis. An analysis of variance was carried out on responses corresponding to the Box-Behnken design, with the aim of examining the effect and contribution of different factors, at a 95% confidence level.

Table 4: Fabric classification based on the results of the moisture management tester [24]

Sample code	Type Name	Properties
1	Waterproof fabric (WF)	Very slow absorption, slow spreading, no one-way transport, no penetration
2	Water-repellent fabric (WRF)	No wetting, no absorption, no spreading, poor one-way transport without external forces
3	Slow-absorbing and slow-drying fabric (SA&SDF)	Slow absorption, slow spreading, poor one-way transport
4	Fast-absorbing and slow-drying fabric (FA&SDF)	Medium to fast wetting, medium to fast absorption, small spreading area, slow spreading, poor one-way transport
5	Fast-absorbing and quick-drying fabric (FA&QDF)	Medium to fast wetting, medium to fast absorption, large spreading area, fast spreading, poor one-way transport
6	Water penetration fabric (WPF)	small spreading area, Excellent one-way transport
7	Moisture management fabric (MMF)	Medium to fast wetting, medium to fast absorption, large spreading area and fast spreading at bottom surface, good to excellent one-way transport

3 Results and discussion

Moisture management properties of spunlace nonwoven fabrics
Moisture transport through the nonwoven fabrics was experimentally determined using a moisture management tester. The results are presented in Table 5.

Table 5: Mean value of various indices of moisture management tester with cl

Sample code	Wetting time: Mean [s]/COV [%]		Absorption rate: Mean [%/s]/COV [%]
	Top surface	Bottom surface	Top surface
1	3.98/4.8	9.12/9.05	57.59/3.4
2	4.12/5.1	7.21/4.13	18.61/5.37
3	4.22/5.36	9.55/6.54	82.33/5.72
4	4.45/2.54	7.90/3.74	32.8/8.67
5	9.86/5.33	12.29/6.86	0.0/0.0
6	10.26/7.25	14.37/6.12	0.0/0.0
7	1.96/4.4	9.95/5.95	37.14/9.51
8	2.26/8.02	10.41/5.27	18.87/6.23
9	4.23/2.76	8.31/2.43	34.72/5.68
10	10.56/6.22	13.46/4.19	0.0/0.0
11	10.39/7.24	14.62/6.22	0.0/0.0
12	2.93/3.11	9.27/2.36	26.74/4.19
13	2.71/5.39	9.5/2.56	20.48/9.21
14	4.38/7.29	7.98/5.96	43.06/5.00
15	3.82/6.62	7.62/7.29	44.01/3.22
16	4.33/3.99	8.92/3.05	5.36/3.93
17	3.81/5.34	9.06/6.63	10.43/4.61
18	3.68/4.05	8.42/3.21	37.05/4.73
19	3.38/4.28	8.97/4.37	27.68/8.68
20	3.25/3.90	7.92/2.33	50.148/6.35
21	3.65/6.11	9.84/3.54	71.7/8.21
22	3.85/7.93	8.60/9.27	17.74/7.38
23	9.55/3.94	13.95/2.81	0.0/0.0
24	8.85/4.95	13.44/1.19	0.0/0.0
25	1.88/6.74	9.36/4.37	24.88/9.68
26	1.55/5.02	9.77/6.55	28.72/3.70
27	4.11/3.32	8.11/3.54	30.52/4.22

3.1 Wetting time

Wetting time is defined as the time in seconds when the slope of total water contents at the top and bottom surfaces become greater than tan (15°), the specimen begins to be wetted. Wetting time can be compared with the absorbency drop test specified in AATCC 79. The basic unit of any textile structure is fibre. Generally, the wetting time on the top surface of any fabric is affected by its composition, in addition to the structural arrangement of the fibre it contains. The wetting of the surface is also affected by the interaction between the liquid and the fibre that makes up the fabric. The contact angle between the fibre and the liquid affects the transportation of liquid in both directions, i.e. horizontally and vertically. Hence, a fibre with lower interfacial energy/surface

lassification of type of fabric

Absorption rate: Mean [%/s]/COV [%]		Max. wetted radius: Mean [mm]/COV [%]		Spreading speed: Mean [mm/s]/ COV [%]		One-way transport capability: Mean/COV [%]	Overall moisture management coefficient: Mean/ COV [%]	Remarks on type of fabric
	Bottom surface	Top surface	Bottom surface	Top surface	Bottom surface			
	121.17/8.7	10.0/0.0	10.0/0.0	0.83/9.2	1.16/9.2	449.25/4.84	0.71/8.88	MMF
	69.04/4.97	11.66/8.92	21.66/10.32	2.44/9.14	4.13/8.26	487.34/7.83	0.88/8.49	MMF
	146.03/8.57	8.33/3.48	10.0/0.0	0.73/8.6	0.89/3.6	239.94/3.42	0.67/3.12	FA&SDF
	58.74/10.05	20.0/0.0	20.0/0.0	3.69/3.18	3.98/3.55	395.74/6.27	0.8/5.83	MMF
	246.23/7.35	0.0/0.0	10.0/0.0	0.0/0.0	1.19/9.39	865.06/4.83	0.62/2.97	WPF
	398.79/9.51	0.0/0.0	5.0/0.0	0.0/0.0	0.4/1.36	914.057/5.49	0.57/3.94	WPF
	73.54/7.37	25/0.0	28.33/0.0	5.24/9.19	5.35/5.79	340.88/6.05	0.86/5.22	MMF
	46.01/5.38	13.33/2.29	16.66/2.88	1.64/8.22	2.72/5.09	347.44/8.55	0.66/5.52	MMF
	95.03/3.33	20/7.07	22.5/3.53	3.66/4.60	3.89/4.23	510.77/5.67	0.93/4.16	MMF
	241.21/7.93	0.0/0.0	5.0/0.0	0.0/0.0	0.46/2.8	856.76/2.11	0.65/3.5	WPF
	298.67/5.91	0.0/0.0	5.0/0.0	0.0/0.0	0.39/3.9	1081.61/6.89	0.73/3.95	WPF
	63.35/5.75	18.33/2.88	18.33/2.88	2.78/3.2	2.72/2.92	406.11/9.11	0.78/7.43	MMF
	53.97/8.87	20.0/0.0	20.0/0.0	1.06/7.32	3.13/3.41	385.11/6.86	0.76/4.71	MMF
	130.36/4.68	27.5/3.53	27.5/3.53	5.54/7.04	5.63/6.97	471.18/2.89	0.96/4.43	MMF
	131.78/5.29	27.5/3.53	22.5/3.62	5.55/3.75	5.14/5.24	546.05/2.99	0.97/3.03	MMF
	35.5/5.77	10.0/0.0	18.33/3.14	0.39/6.09	2.19/7.65	245.05/5.21	0.77/4.95	MMF
	46.03/7.34	5.0/0.0	20/0.0	0.83/4.14	3.16/5.66	502.94/3.71	0.76/6.17	MMF
	101.54/5.21	22.5/0.0	22.5/0.0	3.95/3.33	4.39/4.67	564.44/4.96	0.88/3.56	MMF
	153.3/9.23	10.0/0.0	10.0/0.0	0.85/7.87	0.9/8.43	278.86/8.65	0.74/7.75	MMF
	136.59/6.76	26.66/2.93	26.66/2.93	4.73/5.33	5.13/4.72	393.53/7.29	0.94/5.11	MMF
	145.3/4.33	10.0/0.0	10.0/0.0	0.62/6.54	1.43/7.92	336.35/5.61	0.71/6.37	FA&SDF
	87.73/6.89	20.0/0.0	20/0.0	3.12/6.54	3.44/4.72	425.93/5.04	0.81/2.39	MMF
	245.42/5.67	0.0/0.0	5.0/0.0	0.0/0.0	0.67/3.75	526.47/2.58	0.65/3.58	WPF
	239.12/5.28	0.0/0.0	5.0/0.0	0.0/0.0	0.43/1.14	910.41/4.95	0.63/5.26	WPF
	89.51/5.18	20.0/0.0	20.0/0.0	4.3/5.36	4.19/2.18	284.5/3.19	0.79/3.31	MMF
	61.66/4.05	20.0/0.0	20/0.0	3.48/8.80	3.54/5.70	398.57/6.21	0.85/6.86	MMF
	112.32/6.11	20.0/0.0	20.0/0.0	3.29/5.29	3.41/4.90	580.97/2.53	0.91/3.89	MMF

tension should support wetting. The fibre-liquid molecular attraction on the surface of fibrous assemblies dictates the flow of moisture through a textile fabric. The surface tension and dimensional parameters of pores in porous media are the main parameters that affect this fibre-liquid interaction [2, 6].

A statistical analysis of variance (ANOVA) using a backward elimination technique showed that the web composition has a significant effect on the wetting time on the top surface, while the effect of waterjet pressure, web mass and delivery speed was found to be insignificant at a 95% confidence interval (Table 6). The response surface equation in coded units for the mean top wetting time is given in equation (1) with a R^2 value of 0.9755.

$$\text{Top wettig time} = 3.951 - 3.848X_4 + 2.114X_4^2 \qquad (1)$$

The effect of web composition on mean wetting time is shown in Figure 1 using equation 1. It is evident from Figure 1 that the experimental data for top wetting time is fitted to a second order polynomial equation. It is also evident from Figure 1 that and increase in CV content reduces mean wetting time. The surface tension of PET is higher than that of CV for water, while the mean pore diameter of PET nonwoven fabric is higher than that of CV nonwoven fabric. A higher surface tension and higher pore diameter impede the wetting of fabric surface. Hence, the wetting time on the top surface of PET nonwoven fabric is significantly higher than that of CV fabric and 50PET/50CV blended nonwoven fabric (Figure 1).

In the case of blended nonwoven fabric, the properties of individual fibres affect wetting behaviour. The presence of CV expedites the wetting process. Hence, the 50PET/50CV blended fabric demonstrates a lower wetting time on the top surface than the PET nonwoven fabric.

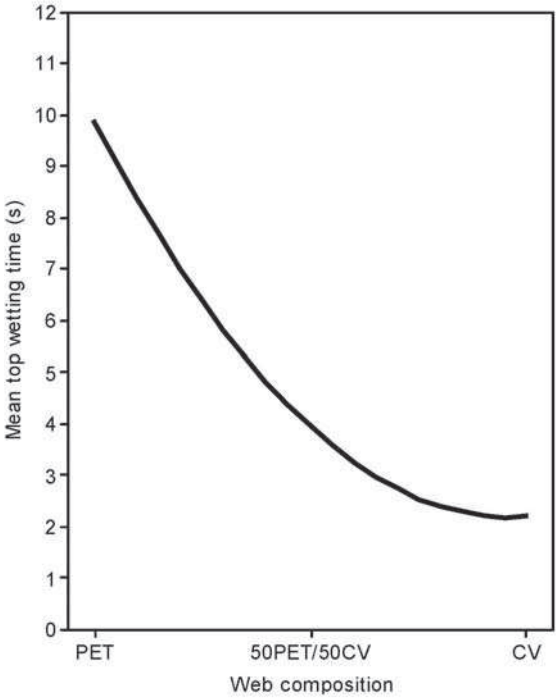

Figure 1: Top wetting time depending on the web composition

The wetting time on the bottom surface was expected to be affected by the ability of the structure to transport liquid. The pore diameter is used to affect wicking in any textile structure. The pore diameter of spunlace nonwoven fabric depends on waterjet pressure, web weight and web composition. Hence, the wetting time on the bottom surface should be affected by a change in these parameters. The results (Table 5) indicate the wetting time of the bottom surfaces is generally higher than the top surfaces for all fabrics.

Table 6: ANOVA for mean top wetting time

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	2	207.4	103.7	478.1	0.000	97.55
X4	1	177.6	177.6	818.9	0.000	83.55
X4*X4	1	29.8	29.8	137.3	0.000	14.01
Error	24	5.20	0.217			2.45
Lack of fit	22	5.0	0.22	2.74	0.302	2.37
Pure error	2	0.2	0.1			0.08
Total	26	212.6				100

Table 7: ANOVA for mean bottom wetting time

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	4	120.77	30.19	97.13	0.000	94.64
X1	1	1.66	1.66	5.33	0.031	1.30
X3	1	3.49	3.49	11.22	0.003	2.73
X4	1	47.48	47.48	152.74	0.000	37.21
X4*X4	1	68.14	68.14	219.22	0.000	53.40
Error	22	6.84	0.31			5.36
Lack of fit	20	6.79	0.34	13.74	0.07	5.32
Pure error	2	0.05	0.025			0.04
Total	26	311.59				100

The statistical analysis of variance (ANOVA) for the mean wetting time on the bottom surface is presented in Table 7. It is evident from Table 7 that the web composition has a significant effect on the wetting time on the bottom surface, while the effect of waterjet pressure and web mass are also significant, although their percentage contribution is very small. Delivery speed is found to be insignificant at a 95% confidence interval. The response surface equation in coded units for the mean bottom wetting time is given in equation 2 with a R^2 value of 0.9464.

$$\text{Bottom wetting time} = 8.502 - 0.372X_1 + 0.539X_3 - 1.989X_4 + 3.197\,X_4^2 \qquad (2)$$

The effect of waterjet pressure, web mass and web composition on the mean wetting time on the bottom surface is shown in Figure 2 using equation 2. It is evident from Figure 2 that PET nonwoven fabric demonstrates a higher bottom wetting time than CV fabric. This is due to the smaller pore diameter and lower fabric thickness of CV nonwoven fabric compared to PET nonwoven fabric [22]. Hence, a decrease in pore diameter and lower thickness leads to better wicking in CV-based nonwoven fabric.

It is evident from Figure 2 that the wetting time on the bottom surface is lower in 50PET/50CV blended nonwoven fabric than in PET and CV

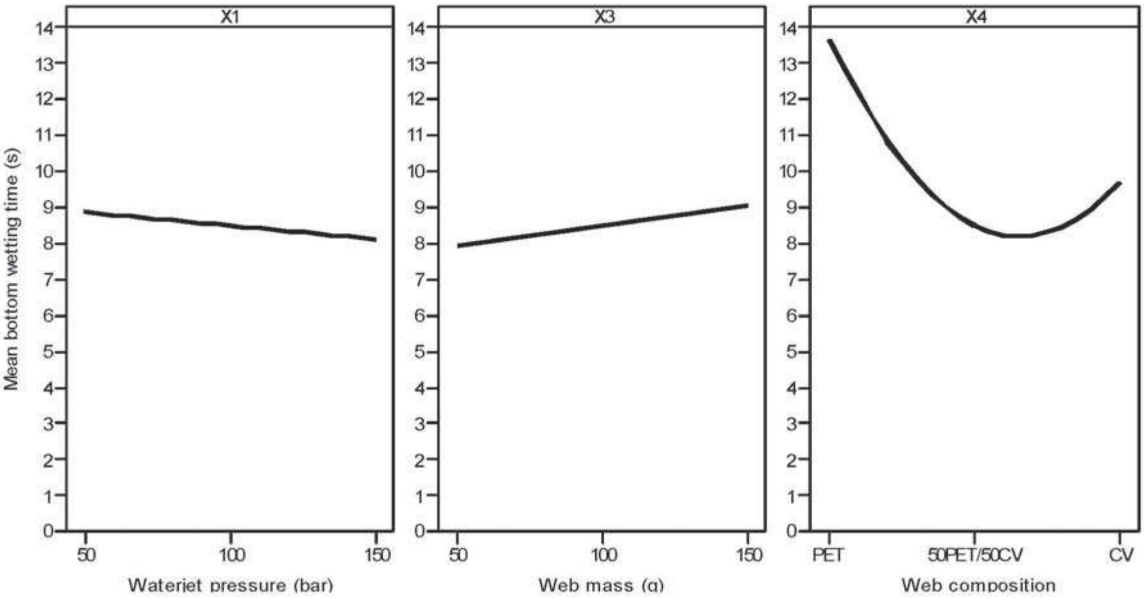

Figure 2: Bottom wetting time depending on waterjet pressure, web mass and web composition

nonwoven fabrics. This is due to the presence of CV fibre, which helps in the quick absorption of liquid/moisture, while PET fibre supports the wicking of liquid. Hence, the wetting time on the bottom surface is lower in 50PET/50CV blend. Table 7 shows that the percentage contribution of web composition is 90%.

It is also evident from Figure 2 that an increase in web mass increases the mean wetting time on the bottom surface. An increase in web mass results in a higher number of water absorbing sites at a molecular level, which delays the wicking phenomenon, despite a lower pore diameter.

The mean wetting time on the bottom surface also depends on waterjet pressure, as shown in Table 7. It is evident from Figure 2 that an increase in waterjet pressure decreases mean wetting time on the bottom surface. An increase in waterjet pressure leads to a decrease in the mean pore diameter and thickness of fabric, [22] which supports the wicking phenomena. Hence, a higher wicking rate reduces the wetting time on the bottom surface.

After the conversion of wetting time values into grades (Table 3), it is evident that nonwoven fabric made of PET, 50PET/50CV and CV exhibits slow (grade 2), medium (grade 3) and fast (grade 4) wetting behaviour on the top surface, and medium (grade 3), medium (grade 3) and fast (grade 4) wetting behaviour on the bottom surface, respectively.

3.2 Absorption rate

The absorption of liquid by a textile substrate indicates the degree of transfer of liquid on its surface. The absorption of liquid by a fabric depends on the type of fibre, fabric structure and openness in the structure. The absorption rate on the top surface of all spunlace nonwoven fabric samples is presented in Table 5.

An ANOVA of the mean absorption rate is presented in Table 8. It is evident from Table 8 that the effect of delivery speed is not significant, while waterjet pressure, web mass and web composition have a significant effect on the mean absorption rate on the top surface. The response surface equation in coded units for mean bottom wetting time is given in equation 3 with a R^2 value of 0.7320.

$$\text{Top absorption rate} = 37.58 - 10.52X_1 - 6.49X_3 + \\ + 13.07X_4 - 24.51X_4^2 - 19.11X_1X_3 \qquad (3)$$

The effect of waterjet pressure, web mass and web composition on the mean absorption rate on the top surface is shown in Figure 3 using equation 3. It is evident from Figure 3 that an increase in waterjet pressure decreases the mean absorption rate on the top surface. This is due to a decrease in fabric thickness, which results in the compactness of the structure at a higher waterjet pressure [22]. Waterjet pressure is a significant parameter for the mean absorption rate on the top surface, as its percentage contribution is more than 10%.

Table 8: ANOVA for the top absorption rate

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	5	9351.2	1870.24	11.47	0.000	73.20
Linear	3	3884.3	1294.78	7.94	0.001	30.41
X1	1	1328.5	1328.5	8.15	0.009	10.40
X3	1	506.2	506.2	3.10	0.093	3.96
X4	1	2049.6	2049.6	12.57	0.002	16.04
Square	1	4006.5	4006.5	24.57	0.000	31.36
X4*X4	1	4006.5	4006.5	24.57	0.000	31.36
2-way interaction	1	1460.3	1460.3	8.96	0.007	11.43
X1*X3	1	1460.3	1460.3	8.96	0.007	11.43
Error	21	3423.8	3423.8			26.80
Lack of fit	19	3401.9	4.20	14.48	0.059	26.63
Pure error	2	21.9	10.96			0.17
Total	26	12775.0				100

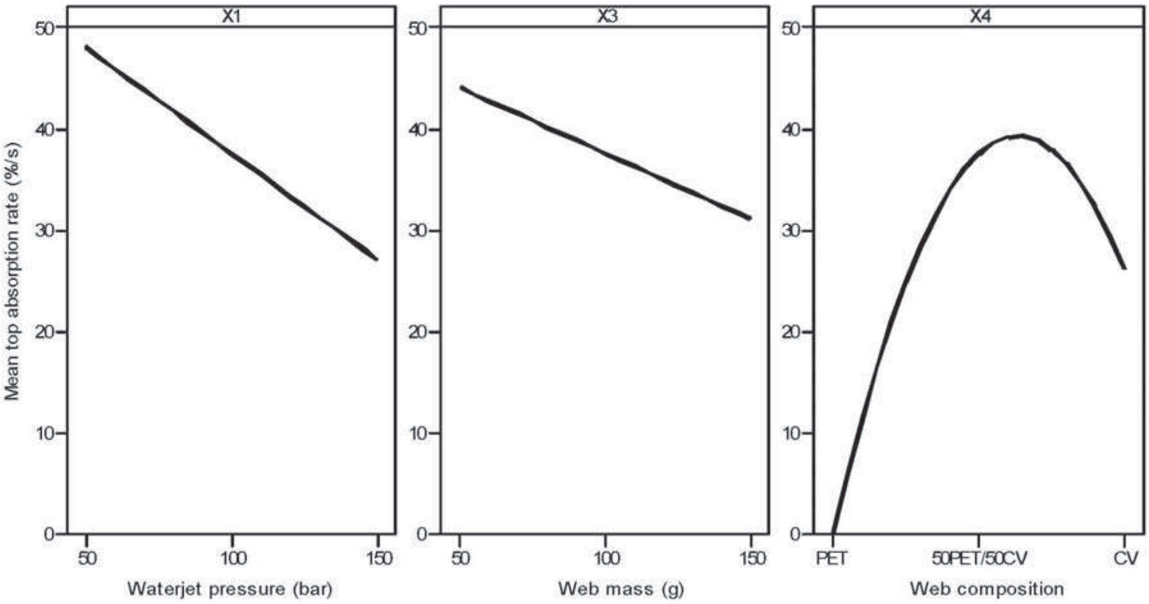

Figure 3: Top absorption rate depending on waterjet pressure, web mass and web composition

The mean absorption rate (%) on the top surface for CV nonwoven fabric is higher than that of PET nonwoven fabric due to the presence of a higher number of hydrophilic sites in the CV nonwoven fabric. The mean absorption rate (%) is higher in 50PET/50CV blended nonwoven fabric than in CV nonwoven fabric (Figure 3). CV nonwoven fabric has good absorbency due to its hydrophilic CV fibre. However, it forms a strong bond with the absorbing group of fibre molecules due to its high affinity to water when water molecules in the capillary flow reach a smaller diameter. This impedes the capillary flow along the channel formed by the fibre surface, leading to a decrease in the mean absorption rate. In the 50PET/50CV blend, the PET fibre helps in the wicking of moisture/water being absorbed by CV fibre, resulting in a higher mean absorption rate.

The effect of web mass on the mean absorption rate is also shown in Figure 3. It is evident that the mean absorption rate for 50 g/m^2 is higher than that for 150 g/m^2. This difference in the mean absorption rate was statistically significant. Nonwoven fabric at a lower web mass demonstrates a higher absorption rate because a fabric with a lower mass is more porous (high pore diameter), which helps in the absorption of moisture at faster rate, while at higher web mass, a compact structure with a smaller pore diameter results in a lower absorption rate.

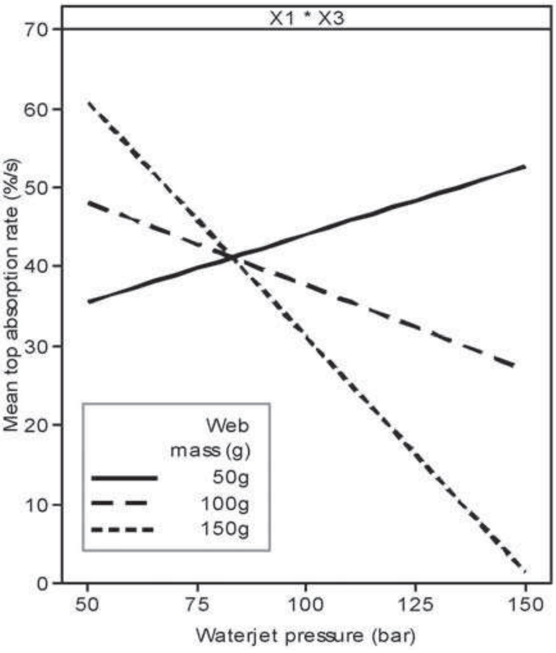

Figure 4: Interaction effect of web mass and waterjet pressure on top absorption rate

The interaction effect of web mass and waterjet pressure on the mean absorption rate on the top surface is shown in Figure 4. It is evident from Figure 4 that at a low web mass, an increase in waterjet pressure increases the mean absorption rate due to a more open structure. The openness of the structure becomes more prominent at a high waterjet pressure and low web mass due to the grouping of fibres. Similarly, a higher web mass and low waterjet pressure result in an increase in the mean absorption rate due to the reduced binding of fibres. A higher web mass and high waterjet pressure lead to a compacted structure, resulting in a decrease in the mean absorption rate.

The mean absorption rate on the bottom surface plays an important role in the moisture management behaviour of any textile structure. A textile structure with a higher bottom surface absorption rate helps to transfer the moisture in the environment, which is wicked through the structure. The mean absorption rate on the bottom surface of spunlace nonwoven fabric samples are presented in Table 5. An ANOVA of the mean absorption rate on the bottom surface is presented in Table 9.

It is evident from Table 9 that only web composition has a significant effect on the mean absorption rate on the bottom surface. The response surface equation in coded units for the mean bottom wetting time is given in equation 4 with a R^2 value of 0.8002.

$$\text{Bottom absorption rate} = 104.7 – 106.8X_4 – 66.8X_4^2 \quad (4)$$

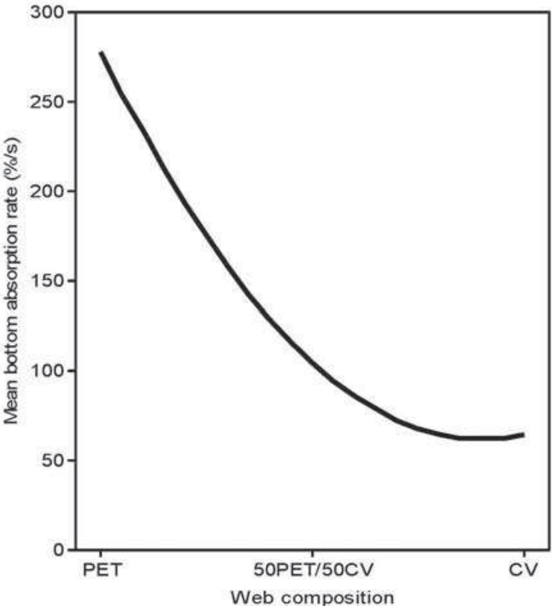

Figure 5: Bottom absorption rate depending on web composition

The effect of web composition on the mean absorption rate on the bottom surface is shown in Figure 5 using equation 4. It is evident from Figure 5 that PET nonwoven fabric demonstrates a significantly higher bottom absorption rate than CV nonwoven fabric. An increase in the CV content in a nonwoven structure leads to an increase in the absorption rate on the top surface. Due to its high affinity to water molecules, however, the CV nonwoven fabric results in the formation of a strong bond between those molecules, which inhibits the capillary flow across the structure, causing a decrease in the absorption rate on the bottom surface.

After the conversion of absorption values into grades (Table 3), PET nonwoven fabric demonstrates a slow absorption rate (grade 2) on the top surface and a very fast absorption rate on the bottom surface (grade 5), while CV nonwoven fabric demonstrates a medium/fast absorption rate (grade 3/4) on the top surface and a medium/slow absorption rate on the bottom surface (grade 3/2). The 50PET/50CV blend exhibited an optimum absorption rate on both

Table 9: ANOVA for the bottom absorption rate

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	2	166544	83272	48.06	0.000	80.02
Linear	1	136832	136832	78.97	0.000	65.74
X4	1	136832	136832	78.97	0.000	65.74
Square	1	29712	29712	17.15	0.000	14.28
X4*X4	1	29712	29712	17.15	0.000	14.28
Error	24	41585	1733			19.98
Lack of fit	22	40933	1860	5.7	0.159	19.66
Pure error	2	652	326			0.31
Total	26	208129				100

the top and bottom surfaces, considering the presence of moisture in the structure.

3.3 Wetted radius

The value of the wetted radius demonstrates the extent of water spread on a textile structure. The wetted radius is directly related to the drying behaviour of a fabric. The value of the wetted radius should be affected by the web composition and web mass of a textile structure. The values of the top surface wetted radius are presented in Table 5. An ANOVA of the mean wetted radius (mm) on the top surface is presented in Table 10. It is evident that, apart from the delivery speed, all other factors have a significant effect on the mean value of the wetted radius on the top surface.

The response surface equation in coded units for the mean top wetted radius is given in equation 5 with a R^2 value of 0.8002.

$$\text{Top wetted radius} = 16.61 + 3.47X_1 - 4.86X_3 + 9.72X_4 - 6.89X_4^2 \quad (5)$$

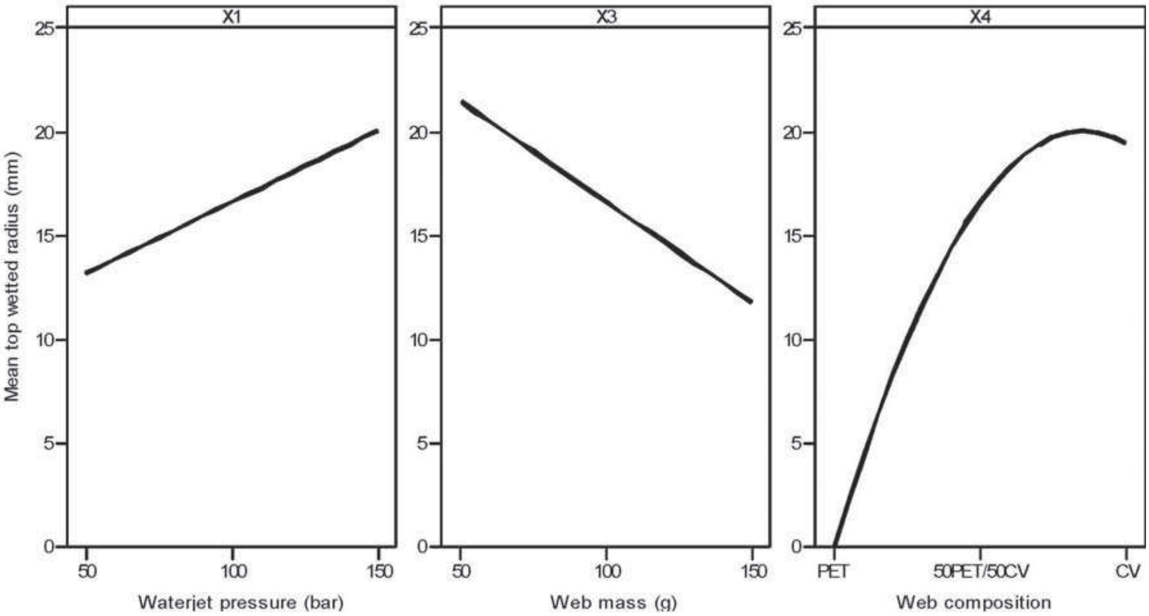

Figure 6: Top wetted radius depending on waterjet pressure, web mass and web composition

Table 10: ANOVA for the top wetted radius

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	4	1878.62	469.65	22.28	0.000	80.20
Linear	3	1562.29	520.76	24.71	0.000	66.70
X1	1	144.63	144.63	6.86	0.016	6.17
X3	1	283.53	283.53	13.45	0.001	12.10
X4	1	1134.13	1134.13	53.81	0.000	48.42
Square	1	316.33	316.33	15.01	0.001	13.50
X4*X4	1	316.33	316.33	15.01	0.001	13.50
Error	22	463.73	21.08			19.80
Lack of fit	20	459.56	22.98	11.03	0.086	19.62
Pure error	2	4.17	2.08			0.18
Total	26	2342.34				100

The effect of significant factors on the mean top wetted radius is shown in Figure 6 using equation 5. It is evident from Figure 6 that an increase in CV content results in an increases in the mean wetted radius on the top surface. When a liquid droplet is introduced on the surface, absorption by the CV component presumably begins before the start of wicking. This facilitates the spreading of moisture. Hence, the mean wetted radius on the top surface increases. The percentage contribution of web composition to the mean wetted radius on the top surface is around 61.92%.

The effect of web mass on the mean wetted radius on the top surface is shown in Figure 6. It can be concluded that an increase in web mass results in a decrease in the mean wetted radius. This is due to an increase in the number of absorptions sites as web mass increases. The percentage contribution of web mass to the mean wetted radius (top surface) is around 12%.

The effect of waterjet pressure on the mean wetted radius on the top surface is shown in Figure 6. It is evident that an increase in waterjet pressure results in an increase in the mean wetted radius on the top surface. Waterjet pressure leads to a more compact structure that better supports the spreading of moisture compared with wicking and/or absorption. The percentage contribution of waterjet pressure to the mean wetted radius (top surface) is around 6%.

The mean wetted radius on the bottom surface demonstrates how well moisture dissipates to the outer environment. The higher the mean bottom wetted radius, the better the moisture dissipation to the environment. The value of the bottom surface wetted radius is presented in Table 5. An ANOVA is also presented in Table 11. It is evident that, besides delivery speed, all other factors have a significant effect on the mean value of the bottom wetted radius. The response surface equation in coded units for mean bottom wetted radius is given in equation 6 with an R^2 value of 0.8728.

$$\text{Ton wetted radius} = 20.971 + 4.166X_1 - 4.12X_1^2 - - 2.917X_3 + 7.36X_4 - 6.41X_4^2 \quad (6)$$

The effect of significant factors on the mean top wetted radius is shown in Figure 7 using equation 6. It is evident from Figure 7 that PET nonwoven fabric has a smaller wetted radius on the bottom surface than CV nonwoven fabric. This is the result of higher moisture wicking than absorbency in PET nonwoven fabric, while an increase in the CV content results in an increase in the mean wetted radius on the bottom surface. This is due to the hydrophilic nature of CV fibre. Absorption by CV fabric appears to be predominant, while the bottom wetting radius increases as the quantity of CV fibre is increased. The percentage contribution of web composition to the mean wetted radius on the bottom surface is around 60%.

The effect of waterjet pressure on the mean bottom wetted radius is shown in Figure 7. It is evident that

Table 11: ANOVA for the bottom wetted radius

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	5	1276.57	255.31	28.81	0.000	87.28
Linear	3	960.37	320.12	36.13	0.000	65.66
X1	1	208.25	208.25	23.50	0.000	14.24
X3	1	102.08	102.08	11.52	0.003	6.98
X4	1	650.04	650.03	73.36	0.000	44.44
Square	2	316.20	158.10	17.84	0.000	21.62
X1*X1	1	53.54	53.54	12.23	0.002	3.66
X4*X4	1	262.66	262.66	29.64	0.000	17.96
Error	21	186.07	8.86			12.72
Lack of fit	19	181.90	9.57	4.60	0.194	12.44
Pure error	2	4.17	2.08			0.28
Total	26	1462.64				100

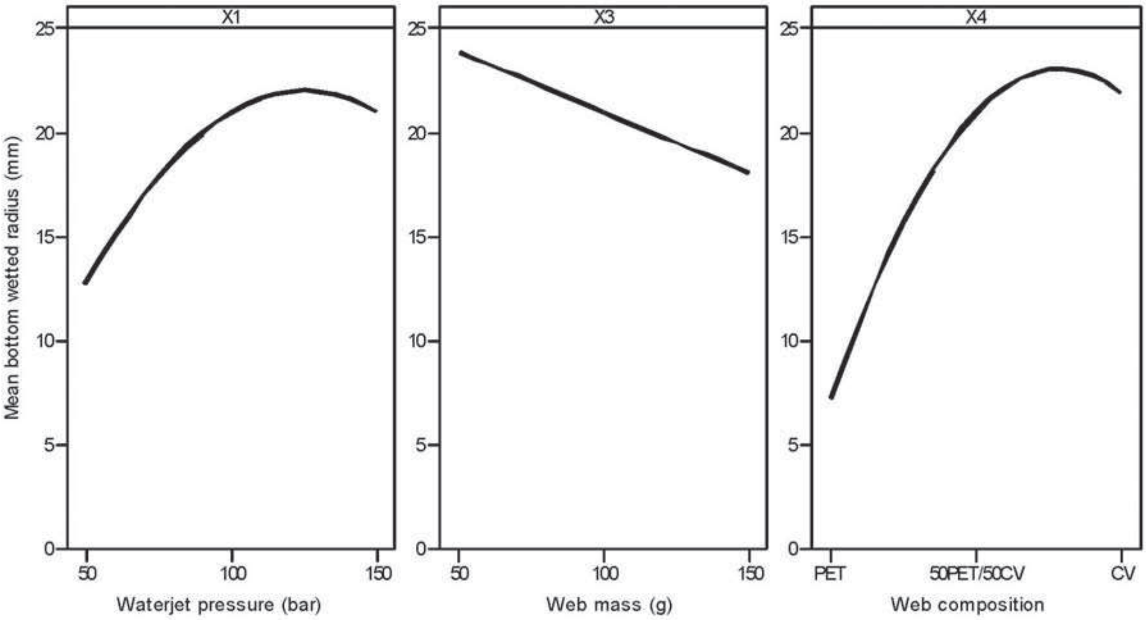

Figure 7: Bottom wetted radius depending on waterjet pressure, web mass and web composition

an increase in waterjet pressure results in an increase in the mean wetted radius on the bottom surface. When waterjet pressure is increased, the structure consolidates and the pore size is reduced with a reduction in fabric thickness. The lower diameter of capillary flow facilitates wicking. Hence, moisture transmission from the top surface is faster. This wicked moisture is diffused faster than additional wicking [25] due to the compactness of the structure. This leads to an increase in the bottom wetted radius. The percentage contribution of waterjet pressure to the mean wetted radius (top surface) is around 17%.

The effect of web mass on the mean bottom wetted radius is shown in Figure 7. It is evident that an increase in the web mass results in a decrease in the mean bottom wetted radius. An increase in the number of absorption sites through an increase in web mass leads to a reduction in the openness of the structure, which in turn results in an increase in the mean wetted radius. The percentage contribution of web mass to the mean wetted radius (top surface) is around 6%.

After the conversion of wetted radius values into grades (Table 3), PET nonwoven fabric demonstrates a minimum wetted radius (grade 1) on both the top and bottom surfaces. CV nonwoven fabric demonstrates a good wetted radius (grade 4) on both the top and bottom surfaces, while the 50PET/50CV blend exhibits the best wetted radius on both the top surface and bottom surface.

3.4 Spreading speed

The spreading speed of moisture/liquid on a textile substrate indicates the degree of moisture dispersion in a fabric. The spreading speed of moisture/liquid in a fabric depends on the type of fibre, fabric structure and openness of the structure (pore size). The spreading speed of moisture on the top surface of all spunlace nonwoven fabric samples is presented in Table 5. An ANOVA of the mean wetted radius (mm) on the top surface is presented in Table 12. The response surface equation in coded units for the mean spreading speed on the top surface is given in equation 7 with a R^2 value of 0.7238.

$$\text{Top spreading speed} = 3.245 + 0.769X_1 - 1.057X_1^2 - \\ - 1.276X_3 + 1.542X_4 - 1.35X_4^2 \quad (7)$$

The effect of significant factors on the mean spreading speed on the top surface is shown in Figure 8 using equation 7. It is evident from Figure 8 that an increase in CV content results in an increase in the mean spreading speed. This is due to the higher mean wetted radius on the top surface with a higher CV content, while the hygroscopic nature of CV nonwoven fabric leads to a higher top spreading speed. The percentage contribution of web composition to the mean spreading speed on the top surface is around 40%.

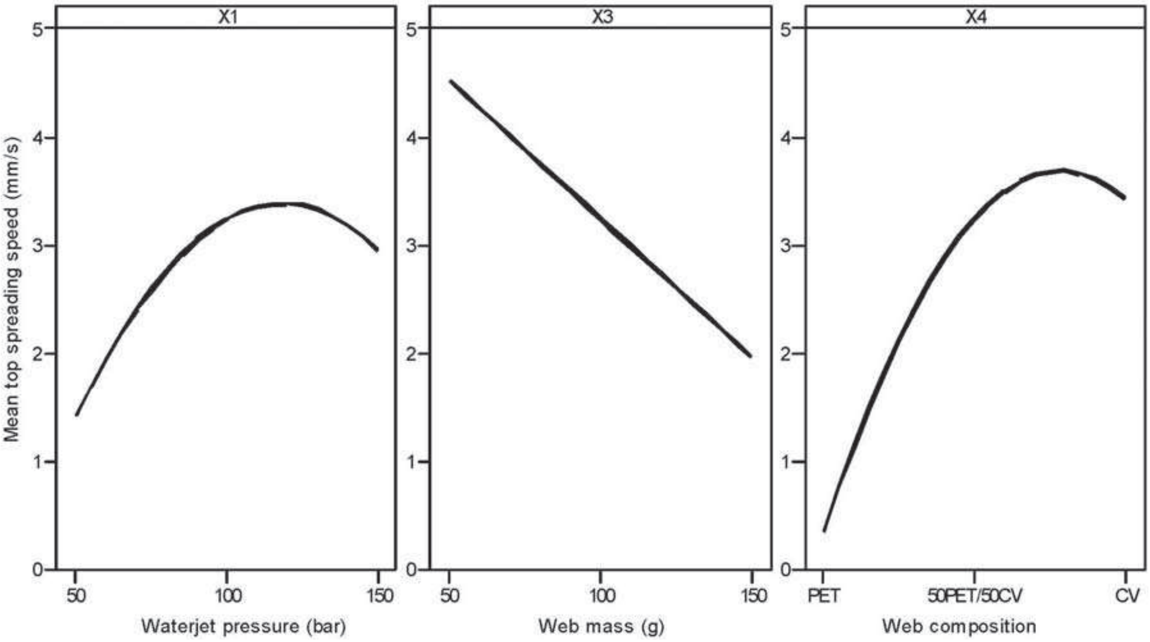

Figure 8: Top spreading speed depending on waterjet pressure, web mass and web composition

The effect of waterjet pressure on the mean wetted radius on the top surface is shown in Figure 8. It is evident that an increase in waterjet pressure results in an increase in the mean spreading speed on the top surface. The higher spreading speed on the top surface is due to a higher mean wetted radius at a higher waterjet pressure. The percentage contribution of waterjet pressure to the top spreading speed is around 10%.

The effect of web mass on the mean spreading speed on the top surface is shown in Figure 8. It can be concluded that an increase in web mass results in a decrease in the mean wetted radius on the top surface. Hence, there is decrease in the mean top spreading speed. The percentage contribution of web mass to the top spreading speed is around 20%. The bottom spreading speed is more important in the moisture management of textile fabrics. A higher

Table 12: ANOVA for the top spreading speed

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	5	70.97	14.19	11.0	0.000	72.38
Linear	3	55.15	18.38	14.25	0.000	56.25
X1	1	7.10	7.10	5.50	0.029	7.24
X3	1	19.53	19.53	15.14	0.001	19.92
X4	1	28.52	28.52	22.11	0.000	29.09
Square	2	15.81	7.90	6.13	0.008	16.13
X1*X1	1	4.13	7.15	5.55	0.028	4.21
X4*X4	1	11.68	11.68	9.06	0.007	11.91
Error	21	27.09	1.28			27.62
Lack of fit	19	26.89	1.41	12.92	0.074	27.40
Pure error	2	0.22	0.11			0.22
Total	26	98.05				100

bottom spreading speed should lead to the quick drying of fabrics. The spreading speed of moisture on the bottom surface of all nonwoven fabric samples is presented in Table 5. An ANOVA analysis of the bottom spreading speed is presented in Table 13. The response surface equation in coded units for the mean spreading speed on the bottom surface is given in equation 8 with a R^2 value of 0.8358.

$$\text{Bottom spreading speed} = 3.816 + 1.053X_1 - 1.047X_1^2 - 0.833X_3 + 1.509X_4 - 1.368X_4^2 \quad (8)$$

The effect of significant factors on the mean spreading speed on the bottom surface is shown in Figure 9 using equation 8. It is evident from Figure 9 that an increase in CV content results in an increase in the mean bottom spreading speed, although a smaller bottom wetted radius was recorded. This is due to the higher moisture absorbency of CV nonwoven fabric compared to PET nonwoven fabric, which induces a high absorption speed with a high spreading speed on the top surface. The higher spreading speed on the top surface and a low wetting time on

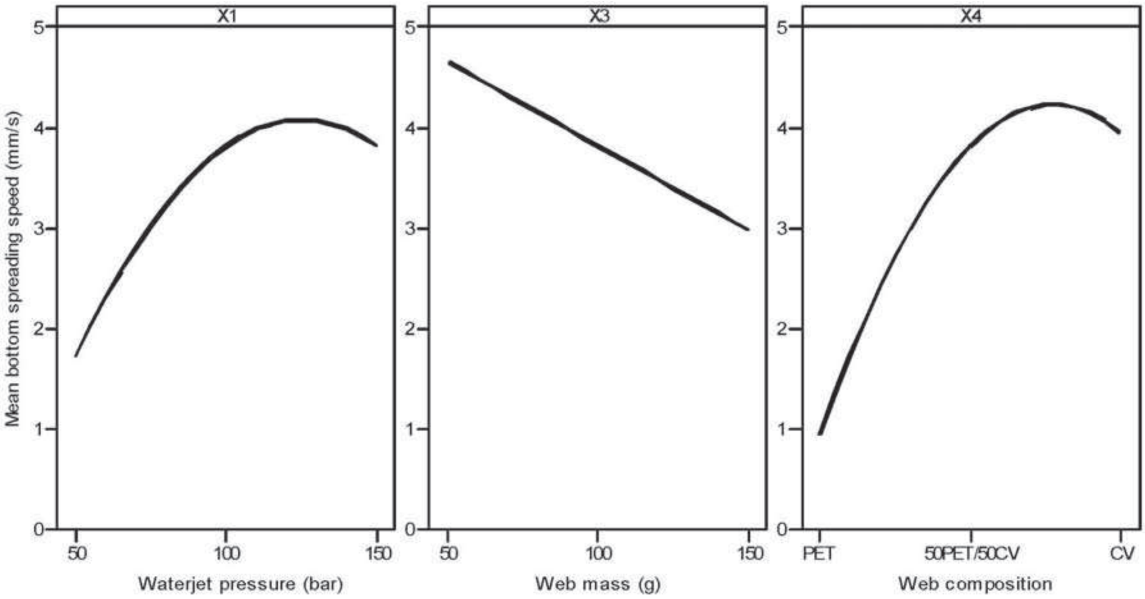

Figure 9: Bottom spreading speed depending on waterjet pressure, web mass and web composition

Table 13: ANOVA for the bottom spreading speed

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	5	64.93	12.98	21.39	0.000	83.59
Linear	3	48.97	16.32	26.88	0.000	63.04
X1	1	13.31	13.31	21.93	0.000	17.14
X3	1	8.33	8.32	13.71	0.001	10.72
X4	1	27.33	27.33	45.01	0.000	35.18
Square	2	15.96	15.96	13.14	0.000	20.55
X1*X1	1	7.01	7.01	11.55	0.003	5.13
X4*X4	1	11.98	11.97	19.72	0.000	15.42
Error	21	12.75	0.60			16.42
Lack of fit	19	12.27	0.64	2.69	0.306	15.80
Pure error	2	0.48	0.24			0.62
Total	26	77.68				100

the bottom surface results in a higher spreading speed on the bottom surface. The percentage contribution of web composition to the mean spreading speed on the bottom surface is around 50%.

The effect of waterjet pressure on the mean bottom spreading speed is shown in Figure 9. The mean bottom spreading speed was found to increase with an increase in waterjet pressure. It was previously found that increased waterjet pressure results in an increase in the mean bottom wetted radius (section 3.3). Hence, there is an increase in the mean bottom spreading speed. The percentage contribution of waterjet pressure to the mean bottom spreading speed is around 22%.

The effect of web mass on the mean spreading speed on the top surface is shown in Figure 9. It can be concluded that an increase in web mass results in a decrease in the mean wetted radius on the bottom surface. Hence, there is a decrease in the mean spreading speed. The percentage contribution of web mass to the mean bottom spreading speed is around 10%.

After the conversion of the mean spreading speed into grades (Table 3), PET nonwoven fabric demonstrates a very slow spreading speed (grade 1/2) on the top and bottom surfaces. CV nonwoven fabric demonstrates a fast spreading speed (grade 4) on the top and bottom surfaces, while the 50PET/50CV blend also exhibits a medium to fast spreading speed (grade 2/3) on both the top and bottom surfaces.

3.5 One-way transport capability

One-way transport capability is the difference between the amount of liquid moisture content on the top and bottom surfaces of a specimen with respect to time. A positive OWTC value means a higher amount of moisture is transferred from the inner surface to the outer surface of a garment. The one-way transport capability of all fabrics is presented in Table 5. An ANOVA analysis of the mean OWTC is presented in Table 14. It is evident that only web composition has a significant effect on the OWTC of spunlace nonwoven fabric. The response surface equation in coded units for the mean OWTC is given in equation 9 with a R^2 value of 0.7325.

$$OWTC = 428.6 - 249.3X_4 - 181.2X_4^2 \quad (9)$$

The effect of web composition on the mean OWTC is shown in Figure 10 using equation 9. It is evident from Figure 10 that OWTC is higher for PET fabrics

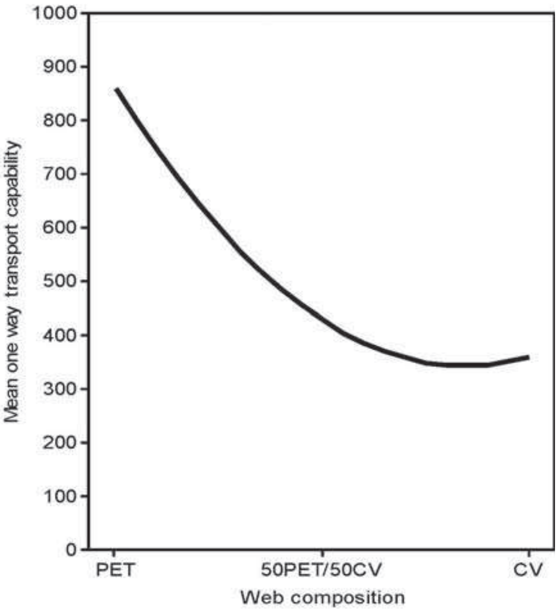

Figure 10: Mean OWTC depending on web composition

Table 14: ANOVA for the mean OWTC

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	2	964755	482377	32.86	0.000	73.25
Linear	1	745884	745884	50.82	0.000	56.63
X4	1	745884	745884	50.82	0.000	56.63
Square	1	218870	218870	14.91	0.001	16.62
X4*X4	1	218870	218870	14.91	0.001	16.62
Error	24	352278	14678			26.75
Lack of fit	22	349584	15890	11.80	0.081	26.54
Pure error	2	2694	1347			0.20
Total	26	1317033				100

than for CV-based nonwoven fabrics. This can be attributed to the hydrophobic nature of PET, which results in the reduced absorption of liquid, and a smaller wetted radius and spreading speed on the top surface. Hence, the PET nonwoven fabric supports the wicking phenomenon, despite a higher pore diameter, resulting in a higher OWTC.

All nonwoven structures demonstrate a fair to very good one-way transport index/capability on the grading scale (Table 3). PET nonwoven fabric demonstrates a very good to excellent one-way transport index, while CV nonwoven fabric and 50PET/50CV blended nonwoven fabric demonstrate good one-way transport behaviour.

3.6 Overall moisture management coefficient

The overall moisture management coefficient is an index of the overall capability of a fabric to transport liquid moisture in multiple directions. A higher OMMC value indicates that a fabric can handle moisture better. The OMMC of all fabrics is presented in Table 5, with the classification of fabric type based on Table 4. An ANOVA of the mean OMMC is presented in Table 15. It is evident that, apart from delivery speed, all other factors have a significant effect on overall moisture management. The response surface equation in coded units for the mean OMMC is given in equation 10 with a R^2 value of 0.7701.

$$\mathrm{OMMC} = 0.8239 + 0.055X_1 - 0.0675X_3 + 0.0708X_4 - 0.1168X_4^2 \qquad (10)$$

The effect of significant factors on the mean OMMC is shown in Figure 11 using equation 10. It is evident from Figure 11 that the overall moisture management coefficient (OMMC) is higher for CV-based fabrics than for PET-based nonwoven fabrics. This is because the smaller pore diameter of CV nonwoven fabric exhibits a smaller wetting time (top and bottom surfaces) with a higher spreading speed and higher wetted radius. These factors together contribute to the absorption, transportation and dispersion of moisture in the structure. Although PET-based nonwoven fabric also demonstrates at good OMMC value due to better one-way transport capability, which helps moisture move through a fabric, its lack of moisture dispersion capacity in the structure leads to the accumulation of moisture in one place. 50PET/50CV blended nonwoven fabric demonstrates a very good transport capability in the presence of PET fibres and better moisture absorption and dispersion due to CV fibres. Hence, the 50PET/50CV blended nonwoven fabric is better than the CV and PET nonwoven fabrics in terms of overall moisture management (Figure 11).

It is evident from Figure 11 that the overall moisture management coefficient (OMMC) decreases with an increase in web mass. A higher wetting time and smaller wetted radius hinder moisture absorption and dispersion. The effect of web mass is negative on the mean OMMC value. Nevertheless, all fabrics exhibited a very good to excellent OMMC value.

Table 15: ANOVA for the OMMC of spunlace nonwoven fabric

Source	Degree of freedom	Sum of square	Mean square	F value	P value	Percentage contribution [%]
Model	5	0.265	0.053	13.98	0.000	76.90
Linear	3	0.155	0.052	13.71	0.000	45.25
X1	1	0.036	0.036	9.62	0.000	10.58
X3	1	0.059	0.059	15.58	0.001	17.13
X4	1	0.060	0.06	15.95	0.000	17.54
Square	2	0.11	0.055	14.39	0.000	31.65
X1*X1	1	0.01	0.01	4.12	0.003	1.09
X4*X4	1	0.10	0.10	27.79	0.000	30.56
Error	21	0.080	0.004			23.10
Lack of fit	19	0.079	0.004	6.48	0.142	22.73
Pure error	2	0.001	0.001			0.37
Total	26	0.345	0.345			100

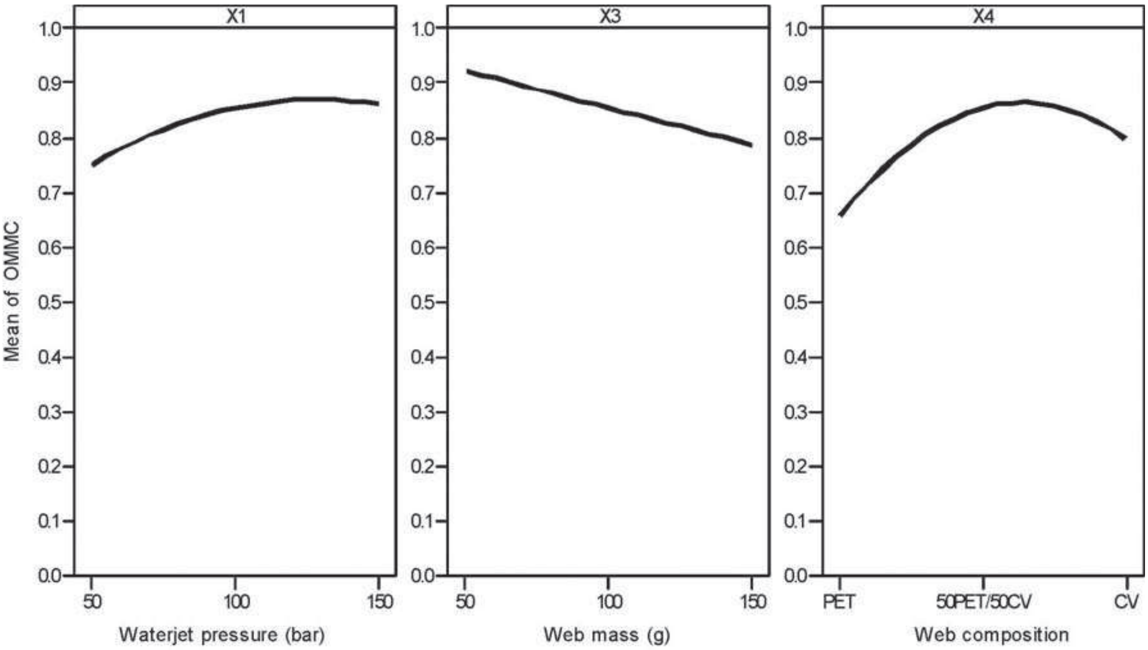

Figure 11: Mean OMMC depending on waterjet pressure, web mass and web composition

It is evident from Figure 11 that OMMC increases with an increase in waterjet pressure. This is because the higher relative frequency of the smaller pore diameter [22] at a higher waterjet pressure helps in the wicking phenomenon. Moreover, a smaller wetting time and higher wetted radius at a higher waterjet pressure help in proper moisture absorption and dispersion.

4 Conclusion

This study encompasses the performance of spunlace nonwoven fabrics for moisture management behaviour. It also explains the effect of different processing parameters on moisture management in spunlace nonwoven fabrics. This experimental study reinforces the fact that web composition is a major factor in determining the comfort of fabric in terms of moisture management. It has a significant effect on all attributes of the moisture management tester. The PET nonwoven fabric was seen as a water penetration fabric due to the hydrophobic nature of PET, which supports liquid/ moisture wicking at a minimal absorption rate and spreading speed. The CV nonwoven fabric was found to exhibit excellent moisture management behaviour. The hydrophilic nature of CV fibre facilitates a high rate of absorption with a smaller wetting time, while a higher OWTC due to the smaller pore diameter leads to a higher bottom spreading speed and higher bottom wetted radius, resulting in the moisture management of the fabric. The 50PET/50CV blended nonwoven fabric was also shown to be a moisture management fabric. An analysis of moisture management tester results shows that all nonwoven fabrics demonstrated a good OMMC. The interaction of all parameters had no significant effect on the OMMC. Hence, individual parameters can be easily chosen to achieve the required OMMC. A higher waterjet pressure leads to a higher OMMC due to the higher relative frequency of the smaller pore diameter in nonwoven fabric, which supports the transfer of moisture/liquid. A higher web mass attenuates the OMMC value. This reduction can be overcome, however, by producing fabric with a higher waterjet pressure and through the proper selection of web composition. Hence, nonwoven fabric with either a CV or 50PET/50CV blended composition, using a higher waterjet pressure and higher web mass, may be used to develop apparel with the required moisture management properties.

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