Influence of selected production parameters on the hand of mattress knitted fabrics assessed by Fabric Touch Tester

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1. Abstract

The overall comfort of a bedding system is, among others, the result of moisture and thermal management capabilities of its components including mattress ticking fabrics. The hand of mattress ticking fabrics, their smoothness, softness, flexibility and thermal properties in particular, partially contribute to the sleep quality. Manufacturers pay a great deal of attention to this aspect and make efforts to improve fabric hand as customers always touch and squeeze the fabric and the perceived fabric hand will partially influence their buying decision. In this study the hand of twelve mattress fabrics was investigated by the Fabric Touch Tester (FTT), which is a relatively new characterization method of fabric hand. FTT measures simultaneously thirteen fabric indices related to four categories of fabric physical properties such as bending, compression, thermal and surface properties. These fabric indices are subsequently used by the FTT software to predict three primary comfort indices (i.e. smoothness, softness, warmth) and two global comfort indices (i.e. total hand and total feel). The fabrics were differentiated by three production parameters namely fabric mass per unit area, concentration of softener and fiber composition. Relevant tactile properties for mattress ticking fabrics such as smoothness, softness, warmth and flexibility were assessed by an expert panel and the average scores given by the assessors were correlated with the fabric indices measured by FTT. Among the selected variables, fabric mass per unit area has the greatest influence on all FTT fabric indices. Due to the large fabric set, considerable variances were observed between the scores assigned by the panels. That resulted in poor correlations between tactile properties and selected production parameters, although the trend seems to be correct and all the factors were found statistically significant. Strong correlations were found between the FTT fabric indices and tactile properties assessed by the panels, except warmth, which suggests that FTT is suitable to assess mattress ticking fabrics with elevated mass per unit area and uneven texture.

Key words: mattress ticking fabrics, fabric hand, FTT, subjective assessment

2. Introduction

Sleep is a vital and basic activity of humans and a psychological need for the human body. Its quality is affected by factors such as room and bed microclimate. Various studies have been conducted using electroencephalogram monitoring to study the effect of temperature on sleep and to identify a thermoneutral zone, defined as the range of optimum temperatures in which the human body feels thermally comfortable (Amrit, 2007). Some studies (Muzet, 1984; Amrit, 2007) indicated that the thermoneutral zone in the bedding microclimate is around 30°C and the preferred ambient temperature 19°C. Moving away from the thermoneutral zone increases the number and duration of wakefulness periods. For instance, high nocturnal awakening was noted, at an ambient temperature of 13°C and a temperature in the microclimate of 26.1°C (Muzet, 1984, Amrit, 2007). Although both temperatures above and below the thermoneutral zone have disruptive effects on sleep patterns, cold ambient temperatures tend to be more disruptive to sleep than warm ambient temperatures, therefore thermoregulation of bedding textiles must be more effective towards cooler temperatures. (Haskell, 1981, Amrit, 2007). Heat loss in bedding occurs through leakage of microclimate air to ambient temperature through bedding upper layers and with the conduction of heat to the mattress. Temperature drops in the bedding microclimate also occur due to the ventilation effect, therefore duvets should not only have insulating, moisture absorbing and temperature compensating effects, but they should also adapt to the body shape (Amrit, 2007). Moreover the heat related sleep disruption tends to concentrate more on initial sleep segments (Mizuno, 2005). The thermoneutral zone has minor variations in various groups, for instance between men and women, elderly and young, and people from different geographical locations (Amrit, 2007).

Sleepwear, bedding textile and mattress ticking fabrics all contribute to the overall perception of comfort, in addition to ambient and bed microclimate. Sleepwear and bedding textiles have close contact to the skin, therefore their tactile properties are extremely important (Meinander, 2002), especially in events of lying in bed for a longer period of time, which may be the case for elderly or disabled people. The importance of adequate surface properties meant to control friction and pressure between the skin and bedding textiles was highlighted within an European study (TAGS, 2013) in which employees from caregiving institutions were asked to recommend improvements for bedding textiles (Blaylock, 2015). Mattress ticking fabrics with specialty fibers or various surface treatments envisaging easy-care, overall well-being, improved hygiene and microclimate are already existing on the market. Moisture and thermal properties of mattress ticking fabrics have a great contribution to the overall sleep comfort. Several studies investigated various possibilities of enhancing thermal comfort of these fabrics and evaluated their thermal properties, water vapour and air permeability accordingly. For instance, the influence of selected design parameters (i.e. fabric tightness, fabric design and *Outlast*® fiber composition) on thermal comfort of knitted spacers used as mattress ticking fabrics was investigated by Onal *et al.* (Onal, 2012). They concluded that fabric thickness has a significant influence on fabric thermal properties, except thermal diffusion and that elevated *Outlast*® fiber composition lead to a high thermal absorptivity and caused thus a cool feeling. In another study (De Mey, 2014), four types of mattresses ticking fabrics differentiated by raw materials (cotton, viscose-polyester, wool) and mass per unit area were padded with Phase Change Materials (PCMs) aiming at thermal comfortable bed systems. This study gives no details about the heating element (stainless steel conductive yarn and respective sewing pattern) but claims that the best results were achieved with the highest PCMs concentrations and that the PCM loaded fabrics kept temperature stable during the cooling process for about 110 seconds. A more recent study (Terliksiz, 2015) has analyzed the thermal comfort of commercially available jacquard knitted mattress ticking fabrics with various fiber content and also found that fabric thickness is the most important parameter for a comfortable sleep environment. Within another study (Tan, 2015) thermal comfort of an innovative four-layer sandwiched mattress was subjectively analyzed by a panel of ten participants. The perception of the thermal comfort was quite subjective, therefore the authors recognize the need for an additional study to objectively assess the thermal comfort of the two mattresses designed.

Unlike thermal comfort, tactile properties of mattress ticking fabrics were less investigated. Within an European research project (All4Rest, 2013), a new generation of mattresses, pillows, bedding textiles and nightwear systems was developed aiming at enhanced sleep comfort. Among others, several natural fibers (i.e. hemp, bamboo, chitosan, soya, etc.) were screened for their potential usage in mattress ticking, pyjamas and bedding textiles. Their tactile properties were evaluated by the Kawabata Evaluation System (KES) and the results highlighted elevated THV (Total Hand Value) of the soya, chitosan and bamboo fabrics as compared with cotton fabrics. (DeVilder 2013). To our best knowledge no further studies exists that investigate the hand of mattress ticking fabrics. Nevertheless the authors believe that particularly smoothness and softness of these fabrics also significantly contribute to sleep quality and that fabric flexibility additionally influences further fabric processing (e.g. sewing of the mattress cover). Moreover during the purchasing phase, customers always touch and squeeze the fabric and the perceived fabric hand will eventually, together with other criteria, influence their buying decision. Therefore manufacturers pay a great deal of attention to this aspect and make efforts to improve the fabric hand. Fabric hand properties may be objectively assessed by well-established methods and instruments (Behery, 2005) among which KES-F, FAST and PhabrOmeter and the results can be further correlated with the results from subjective evaluation involving expert or non-expert panels. Both objective and subjective methods have their limitations in terms of type of properties measured, easiness in handling and interpretation of results, time and costs. For instance, PhabrOmeter measures only the drape, FAST and KES-F systems measure simultaneously compression, bending, extension and respectively compression, bending, surface and tensile properties by using distinct modules. None of these three instruments measures the thermal properties and separate instruments are necessary to measure each of the fabric properties. (Liao, 2014). Fabric Touch Tester (FTT) was quite recently developed by SDL Atlas (SDLAtlas, 2012) in collaboration with the Hong Kong Polytechnic University and claims to overcome some drawbacks of the well-established methods and instruments. FTT is an integrated instrument that can simultaneously measures four kinds of physical properties of the fabric (i.e. compression, bending, surface and thermal properties) and generate thirteen fabric indices. These fabric indices are further employed to compute three primary comfort indices such as softness, smoothness and warmth as well as two global indices called total hand and total feel. Fabrics for clothing have been investigated by mean of this instrument (Hu, 2006) and their tactile properties such as smoothness, softness, prickliness, warmth and dampness were subjectively evaluated by panels. The relationship between these tactile properties and fabric properties measured with FTT was statistically described by prediction models with a R^2 in the range of 0.695 and 0.97. A later study (Liao, 2014) describes the mechanical designs of the four modules of the instrument and respective FTT indices. Subjective evaluations conducted by the panels, statistical results (e.g. ANOVA for discrimination and Gauge R&R for repeatability) and the correlations between the score given by the panels and FTT indices were further discussed in this paper. In another study (Vasile, 2016), sensorial comfort of fabrics for protective clothing was assessed by FTT and it was found that this instrument is sensitive enough to discriminate between fabrics with comparable mass per unit area or thickness. Other studies (Vasile, 2017), (Touche, 2016) report about the ability of the FTT to discriminate between primary comfort indices of knitted fabrics differentiated by yarn type (i.e. ring-spun yarns and air-jet yarns) and finishing treatments. This instrument was also employed to assess tactile properties of fabrics consisting of various man-made cellulosic materials (e.g. Tencel®, Modal) and good agreements were reported between the FTT comfort indices (e.g. softness, smoothness) and expert panels as well as between the smoothness and softness determined by FTT and by Tissue Softness Analyzer (TSA) (Abu Rous, 2016).

To our best knowledge, FTT was not previously used to analyze mattress ticking fabrics, which differ by architecture from clothing textiles and also exhibit elevated mass per unit area. Moreover none of the existing FTT-related studies, report on the influence of production settings on the FTT fabrics indices, primary or global comfort indices. Mattress ticking fabrics discriminated by several production settings were designed and investigated by FTT and their smoothness, softness, warmth and flexibility was assessed by panels. In this study an attempt is made to correlate the results of the FTT with the results of the panels and develop statistical prediction models which describe the relationship between selected production parameters and fabric tactile properties.

3. Materials and methods

3.1. Materials

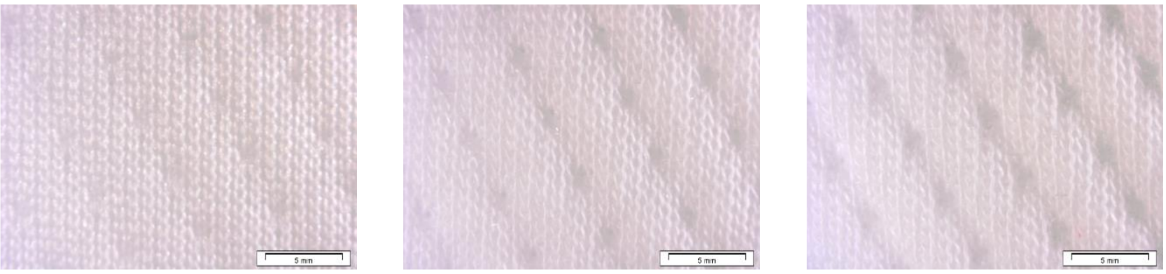
Manufacturers may manipulate and enhance the hand of mattress ticking fabrics by varying several production settings. Fabric mass per unit area, fiber composition or various finishing treatments are examples of parameters that are often tuned during production of mattress ticking fabrics. Double jersey mattress ticking fabrics filled with thick Bulk Continuous Filament (BCF) polyester yarns (PES) in the middle layer, were produced for this study on an industrial double-plate circular knitting machine. The knitted fabrics differentiated by mass per unit area and fiber composition of the upper layer were subsequently impregnated with a silicone softener. Three levels of variation were selected for the concentration of softener and for the mass per unit area, chosen to cover a large range of settings commonly used by manufacturer during production and to enable detection of potential quadratic effects of the input parameters on the FTT fabric indices. The fiber composition was also varied envisaging better hand and thermal properties. For economic reasons, viscose yarns (CV) were used only in the upper layer which is close to the body) and polyester yarns (PES) were used for the backside of all fabrics. The fabrics were developed according to a Design of Experiments (DoE). DoE is a method for systematically planning and conducting experiments by making controlled changes to input variables in order to determine their effect on a given response. The overall objective of such method is to gain maximum amounts of information on cause-effect relationship with a minimum number of experiments (combinations of input factors). A “Custom Design” of JMP software (company SAS) was used in this case (JMP, 2016). There are 18 possible combinations of production parameters (2-level composition, 3 level softener concentration and mass per unit area) and this design recommends a minimum of 9 experiments to be done in order to correctly estimate the effect of the three input variables on the fabric properties measured by FTT. For practical reasons and to enable correct evaluation by the panels, we have arbitrarily limited the total number of experiments to 12. Previous studies (Grineviciute, 2004) noticed a decrease of accuracy of subjective assessments with increase of the number of fabrics and fabrics attributes evaluated.

In Table 1 fabric ID is given according to the combination of the three variables considered. In case of mass per unit area both projected and measured values are given. The data given for mass per unit area and thickness are mean values of 10 specimens and respective standard deviation (SD). In Figure 1 the appearance of three selected polyester fabrics (ID 10, 12 and 8) differentiated by mass per unit area is shown. They were selected to illustrate changes in fabric appearance due to its weight and this aspect will be hereafter discussed.

Table 1 Characteristics of the twelve fabrics produced according to a design of experiments

Fabric ID	Composition of the upper layer		Mass per unit area m (g/m^2) (SD)		Softener concentration Soft (g/l)	Thickness (mm) at 4.14 kPa (SD)
	Fibre	Code	Projected	Actual		
1	PES	0	560	559.96 (19.40)	100	3.62 (0.10)
2	CV	1	560	556.02 (29.90)	100	3.16 (0.25)
3	PES	0	560	546.62 (24.07)	20	3.53 (0.32)
4	CV	1	185	193.58 (5.76)	5	1.09 (0.06)
5	CV	1	275	276.98 (4.96)	20	2.01(0.03)
6	CV	1	185	218.06 (4.19)	100	1.29 (0.02)
7	PES	0	185	183.6 (4.08)	20	1.16 (0.07)
8	PES	0	560	549.12 (25.42)	5	3.49 (0.16)
9	PES	0	185	191.64 (3.25)	100	1.20 (0.03)
10	PES	0	185	186.94 (4.31)	5	1.09 (0.04)
11	CV	1	560	557.86 (22.86)	5	3.55 (0.09)
12	PES	0	275	283.54 (3.49)	5	1.97 (0.04)

PES: polyester; CV: viscose.



a) b) c)

Figure 1 Texture of a) fabric ID 10 (185 g/m^2), b) fabric ID 12 (275 g/m^2) and c) fabric ID 8 (560 g/m^2); magnification x 6.3

3.2 Objective assessment of fabric hand properties by FTT

The FTT equipment measures thirteen fabric indices for the inside (I) and outside (O) of the fabric. In our case, the outside of the fabric refers to the face-side of the mattresses ticking fabrics which is close to the body. In total twenty specimens were used of which ten were used to assess the face-side of the fabric and the rest for the back-side. No standards currently exist for the FTT, therefore the fabrics were tested according to the testing protocol of the equipment manufacturer. The specimens were conditioned prior to testing for a period of 24 h, at 20 ± 2°C and 65 ± 4 % relative humidity. The twelve fabrics were tested by FTT resulting in thirteen fabric indices as displayed and explained in Table 2. Fabric indices (except compression and thermal properties) are simultaneously measured in wale (a) and course direction (e) due to an L-form of the specimens. Details about the measuring modules of the instrument and calculation of these indices are given elsewhere (Hu J. H., 2005) and (Liao, 2014). These FTT fabric indices are subsequently used by the FTT software to predict three primary comfort indices (i.e. smoothness, softness, warmth) and two global comfort indices (i.e. total hand and total feel). For this calculations, the average values (m) of the fabric indices measured in two directions are used, where appropriate. The primary comfort indices are calculated based on statistical models developed by the FTT manufacturer SDL Atlas after correlating the fabric indices with the comfort indices assessed by a hand panel. FTT distinguishes between active and passive comfort indices which refers to the sensation the fabric will give when assessed with the fingers and during wear respectively. These indices are also computed separately for the inside and the outside of the fabric. In this study, we only discuss the thirteen fabric indices measured by FTT, and disregard the primary and global comfort indices as they would not be suitable for the fabrics considered in our study which are most of them thicker and heavier than clothing fabrics used by the manufacturer of the instrument to generate the comfort models.

Table 2 Definitions of the fabric indices measured by FTT

Fabric Property	FTT Fabric Index	Description	Unit
Bending	BAR	Bending Average Rigidity: force needed to bend per radian	gf mm/rad
	BW	Bending Work: work needed to bend the specimen	gf mm rad
Friction	SFC	Surface Friction Coefficient: friction coefficient on surface with ribbed metal plate	-
Roughness	SRA	Surface Roughness Amplitude: roughness irregular wave amplitude	µm
	SRW	Surface Roughness: Wavelength: roughness irregular wave wavelength	mm
Compression	CW	Compression Work: work needed to compress the specimen	gf mm
	CRR	Compression Recovery Rate: percentage of thickness changes after compressed	-
	CAR	Compression Average Rigidity: forces needed to compress per mm	gf/mm^3
	RAR	Recovery Average Rigidity: forces reflected when recovery per mm	gf/mm^3
	T	Thickness: depth of the materials	mm
Thermal properties	TCC	Thermal conductivity when compression: energy transmitted per degree per mm when compresses the specimen	10^{-3} W/m C
	TCR	Thermal Conductivity when Recovery: energy transmitted per degree per mm when the specimen recovers	10^{-3} W/m C
	Qmax	Thermal Maximum Flux: maximum energy transmitted during compression	W/m^2

3.3 Subjective assessment of fabric tactile properties by panels

Ten assessors evaluated the warmth, smoothness, softness and flexibility of the twelve fabrics on a scale from 1-10, where a score of 10 indicates the warmest, smoothest, softest and most flexible fabric. No reference fabrics were provided, the fabrics were compared with each other. The twelve fabrics were assessed according to AATCC5-2011, evaluation method 8.1.2 [25]. The assessors were experienced textile researchers, five men and five women aged between 37-55 (44.3±5.8). Each assessor received a questionnaire and a set of twelve square (20x20 cm) fabrics. The assessment took place in a conditioned room and the assessors were not blindfolded. The assessors were informed about the procedure and the fabric attributes to be evaluated were explained. The specimen was placed on a nonmetallic surface, with the surface to be evaluated uppermost. The warmth of the fabric was evaluated first by touching the fabric surface with the finger tops. The evaluator then touched the specimen by lightly pressing it with the fingers and the palm of the hand to evaluate its smoothness. Finally, the specimen was picked up and rubbed between thumb and fingertips (i.e. softness evaluation) and then bent to assess its flexibility. The assessors only evaluated the face-side of the mattress ticking fabrics to detect possible variation of tactile properties with fiber composition (polyester or viscose), which was varied only on this side of the fabric.

4. Results and discussions

4.1 Influence of the production parameters on FTT fabric indices

The mean (M) and standard deviation (SD) for the measured fabric indices corresponding to the face-side of ten specimens are given in Table 3. All the indices, except compression and thermal properties, are differentiated by the course (e) and wale (a) direction. As expected, the heaviest fabrics of 560 g/m^2 (ID 1, 2, 3, 8, 11) exhibit the highest bending average rigidity (BAR) and bending work (BW) followed by the samples ID 5 and 12 (275 g/ m^2). Some differences can be seen for the two directions of the fabrics, with highest values of the BAR and BW in course direction (e). The highest work needed to compress the specimen (CW) was registered for the heavyweight fabrics (ID 1, 2, 3, 8, 11) and the lowest for lightweight fabrics ID 4, 6, 7, 9, 10. Similar trend was noticed for the thermal conductivity during compression (TCC) and recovery (TCR). In general, the fabrics (ID 2, 4, 5, 6, 11) containing viscose have higher coefficients of frictions (SFC). All the fabrics, except fabric ID 11, exhibited a higher SFCe in the course direction than in wale direction (SFCa). Most of the fabrics exhibited elevated standard deviations for roughness wavelength and amplitude (SRW and SRA), in both directions.

Table 3 Mean (standard deviation SD) of FTT fabric indices for the face-side of the 12 fabrics, in wale (a) and course (e) direction;

	Fabric ID											
	1	2	3	4	5	6	7	8	9	10	11	12
BARa	3650	2465.0	3767.6	174.9	462.4	202.9	201.41	3448.5	208.1	161.5	2975.1	523.78
	(537.7)	(334)	(375.12)	(25.13)	(54.89)	(25.38)	(22.27)	(84.57)	(19.95)	(8.74)	(640.48)	(95.81)
BARe	5309.7	5492.6	4317.4	176.6	763.3	240.5	222.18	4265,4	196.8	169.2	4470.7	771.58
	(939.8)	(745.84)	(810.49)	(38.34)	(75.75)	(43.9)	(50.89)	(669.9)	(20.51)	(21.2)	(800.49)	(46.23)

BWa	15486.9 (1926.8)	11881.1 (2685.3)	16770.3 (866.89)	787.6 (94.08)	2339.9 (139.9)	978.3 (98.06)	1003.1 (70.51)	16160 (612.61)	1046.7 (86.89)	851.5 (59.29)	16137.2 (1889.5)	2577.09 (238.45)
BWe	28110.7 (3571.4)	26920.7 (2340.6)	24137.4 (3050.4)	945.4 (70.98)	3872.2 (280.28)	1193.6 (113.82)	1036.06 (99.77)	23625.5 (2747.4)	1061.63 (78.13)	912.05 (53.69)	20988.45 (3616.6)	3970.61 (148.54)
CW	2439.6 (225.4)	2614 (143.28)	2484.6 (212.46)	1123.0 (56.65)	1976.6 (136.1)	1937.2 (73.72)	1471.2 (173.17)	2411.3 (185.85)	1472.3 (132.47)	1193.2 (75.31)	2587. (149.65)	1855.4 (150.34)
CRR	0.45 (0.02)	0.48 (0.02)	0.46 (0.01)	0.69 (0.02)	0.56 (0.02)	0.62 (0.04)	0.63 (0.06)	0.46 (0.01)	0.7 (0.02)	0.72 (0.04)	0.45 (0.02)	0.58 (0.03)
CAR	117.7 (13.58)	103.84 (11.96)	116.77 (10.68)	236.8 (33.08)	139.38 (10.69)	131.34 (6.29)	151.37 (15.88)	116.1 (0.96)	161.34 (8.32)	214.9 (17.27)	108.31 (6.66)	148.66 (11.99
RAR	188.8 (19.10)	183.64 (16.18)	194.5 (17.54)	271.1 (21.15)	209.33 (16.69)	192.12 (12)	235.77 (25.09)	205.62 (15.81)	213.89 (18.16)	243.06 (20.54)	196.96 (12.72)	208.12 (16.97)
TCC	61.8 (2.06)	66.02 (4.99)	61.91 (2.76)	43.08 (1.7)	52.08 (1.55)	44.46 (0.75)	41.92 (1.4)	62.75 (1.9)	42.67 (0.97)	42.15 (0.99)	66.86 (4.53)	49.77 (0.7)
TCR	59.62 (2.5)	55.7 (2.02)	58.63 (2.37)	43.95 (1.86)	51.86 (2.43)	44.76 (0.94)	42.7 (1.66)	58.89 (0.79)	43.79 (1.35)	43.24 (1.38)	59.65 (3.65)	49.9 (1.51)
Qmax	552.9 (65.71)	863.56 (124.43)	597.97 (70.64)	703.2 (44.83)	703.4 (61.61)	767.6 (44.7)	505 (12.98)	588.94 (64.77)	515.48 (25.53)	498.3 (19.39)	752.25 (69.36)	545.63 (27.78)
SFCa	0.17 (0.01	0.29 (0.02)	0.23 (0.03)	0.33 (0.02)	0.32 (0.03)	0.32 (0.03)	0.21 (0.01)	0.23 (0.02)	0.21 (0.01)	0.21 (0.01)	0.4 (0.02)	0.27 (0.01)
SFCe	0.38 (0.03	0.4 (0.03)	0.32 (0.03)	0.57 (0.05)	0.52 (0.02)	0.54 (0.04)	0.63 (0.05)	0.32 (0.01)	0.6 (0.04)	0.58 (0.04)	0.27 (0.02)	0.42 (0.03)
SRAa	201.3 (17.67)	378.47 (422.87)	240 (70.21)	99.72 (21.43)	227.3 (67.82)	119.0 (56.31)	143.38 (44.65)	239.97 (120.46)	112.26 (46.54)	94.79 (20.04)	265.91 (69.94)	149.71 (52.7)
SRAe	257.6 (39.76)	255.16 (69.73)	300.16 (43.62)	110.6 (35.51)	240.1 (73.19)	127.5 (53.91)	100.19 (24.79)	315.58 (48)	86.57 (15.62)	103.2 (29.77)	249.53 (26.04)	186.22 (20.91)
SRWa	9.43 (1.5)	10.34 (1.6)	8.7 (1.58)	3.82 (1.04)	9.10 (3.15)	3.62 (1.15)	6.28 (3.51)	7.34 (3.11)	3.47 (1.49)	4.71 (1.95)	8.52 (0.93)	7.95 (3.22)
SRWe	5.75 (0.63)	6.01 (0.81)	5.58 (0.72)	3.74 (1.92)	4.98 (3.06)	3.3 (1.33)	1.81 (0.59)	5.57 (0.54)	2.12 (0.93)	2.82 (1.41)	5.64 (0.43)	5.13 (1.47)

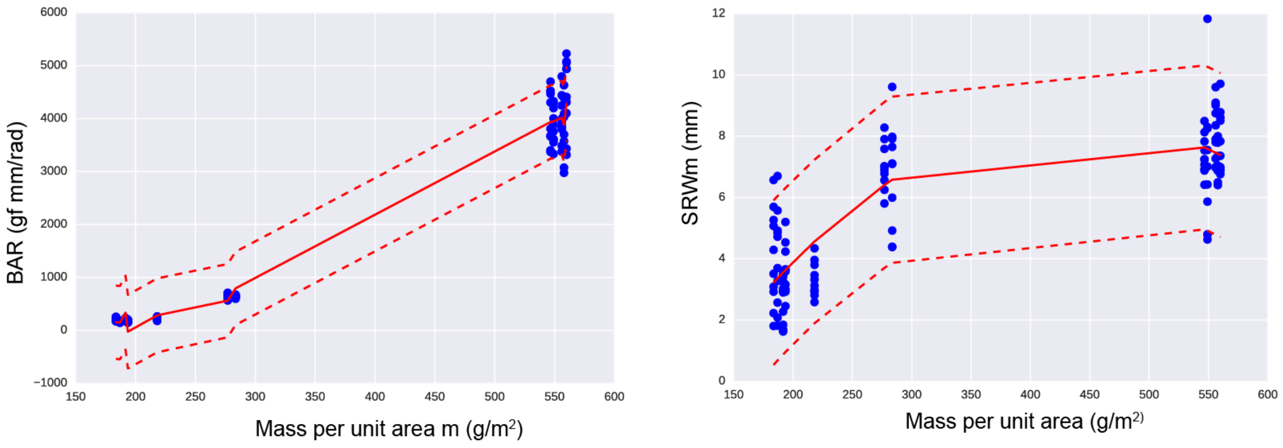
The Python Statsmodels package was used for statistical analysis and to assess the influence of viscose fiber (CV), fabric mass per unit area (m) and softener concentration (Soft) on the fabric properties determined by FTT. The measured values for mass (m) (Table 1) were used in the statistical analysis and the composition of the upper layer was considered as categorical variable (i.e. 0-value for PES and 1-value for viscose CV). A stepwise regression is employed in which an automated procedure selects the predictive variables based on all performed FTT measurements. In each step the remaining unused variables are considered and the variable added that most increases the R^2-adjusted result of the ordinary least squares (OLS). At the same time we collect the relevance of the obtained coefficients as terms are added. The last generated model with all terms significant (the two-tailed p-value for the statistics <0.05) is retained as a valid model. For a level of significance $\alpha=0.05$, mass per unit area (m) was found to have a significant influence on all FTT-measured fabric properties. The statistical models found are listed in Table 4. The sign of the coefficients of the statistical models indicates a strong positive (+) or negative (-) influence of the respective variable on FTT fabric indices considered and high R^2-values (i.e. above 0.8) indicate a strong FTT indices-input variable relationship.

Table 4 Influence of fabric mass per unit area (m), softener concentration (Soft) and viscose (CV) on FTT fabric indices

FTT fabric indices	R^2 adj	Statistical model
BARa	0.94	$BARa= 12.10^{-3} m^2 -411 CV -0.17 Soft^2+17 Soft -232$
BARe	0.94	$BARe= 17.10^{-3} m^2 + 4.70 Soft– 656$
BARm	0.97	$BARm= 14.10^{-3} m^2-206 CV +1.73 Soft -362$
BWa	0.97	$BWa= 54.10^{-3} m^2 -1287 CV -0.134 Soft^2 – 280$
BWe	0.96	$BWe= 88.10^{-3} m^2 +22.52 Soft -1251 CV – 2734$
BWm	0.98	$BWm= 71.10^{-3} m^2 -1216 CV – 1380$
CAR	0.69	$CAR= -1.08 m + 1.2.10^{-3}m^2 -2.57 Soft + 21. 10^{-3} Soft^2 + 379$
RAR	0.52	$RAR=-0.94 m - 0.33 Soft +0.0011 m^2 + 387$
CRR	0.83	$CRR= -2. 10^{-3} m + 2.10^{-6} m^2 + 1.02$
CW	0.85	$CW= 12.3 m – 1.2. 10^{-3} m^2 +17.9 Soft -0.15 Soft^2 - 695$
Qmax	0.77	$Qmax = 216 CV + 0.21 m +3. 10^{-3} Soft^2 + 456$
SFCa	0.82	$SFCa= 0.12 CV – 2.2.10^{-3} Soft + 1.6.10^{-5} Soft^2 + 0.25$
SFCe	0.89	$SFCe= -2.7.10^{-3} m + 3.10^{-6} m^2 + 4.7.10^{-3} Soft - 3.9.10^{-5} + 0.95$
SFCm	0.88	$SFCm=-0.94.10^{-3} m + 62.10^{-3} CV + 8.10^{-7} m^2 + 0.55$
SRAa	0.37	$SRAa=0.32 m + 68.44$
SRAe	0.74	$SRAe= 2.5 m – 2.7. 10^{-3} m^2 – 0.21 Soft + 2.01 Soft - 288$
SRAm	0.72	$SRAm=1.68 m-1.7. 10^{-3} m^2 – 26. 10^{-3} SOFT^2 + 2.65 Soft – 166.44$
SRWa	0.45	$SRWa= 0.042 m -8.2.10^{-5} m^2 -1.5.10^2 Soft^2 + 0.16 Soft -7.86$
SRWe	0.60	$SRWe= 0.05 m - 6.10^{-5} m^2 -5.36$
SRWm	0.65	$SRWm= 0.07 m - 8.1.10^{-5} m^2 -7.19$
T	0.98	$T= 14. 10^{-3} m - 10^{-5} m^2 - 0.13 CV - 1.14.10^{-4} Soft^2 + 11. 10^{-3} Soft – 1.17$
TCC	0.96	$TCC=0.11 m + 2.72 CV - 7.1.10^{-5} m^2- 1.03.10^{-4.} Soft^2 + 23.2$
TCR	0.89	$TCR=0.147 m – 0.143. 10^{-3} m^2 + 20.5$

a: wale direction; e-course direction

Among the selected factors, fabric mass per unit area (m) has a dominant effect on all fabric indices, except surface friction coefficient in wale direction (SFCa). This relationship is linear or quadratic. For instance, the bending indices quadratically increase with increasing mass (m). The same was noticed for the compression indices (except compression work CW) and surface friction coefficient in course direction (SFCe). Compression work (CW) also is strongly influenced by mass per unit area, but the relationship is linear. It was quite expected that heavy fabrics will require high compression work to be bend or compressed. Moreover thermal conductivity during compression (TCC), during recovery (TCR) and fabric thickness (T) exhibit a strong relationship with the fabric mass per unit area. In Figure 2 examples are given that illustrates the strong influence of mass per unit area (m) on (a) bending average rigidity (BAR) and (b) average surface roughness wavelength (SRWm). In Figure 2 the full line indicates the predictive model as shown in Table 4, the dots represent the measurements and the dotted lines are the confidence bands.



a) b)

Figure 2 Influence of fabric mass per unit area (m) on (a) bending average rigidity (BAR) and (b) average surface roughness wavelength (SRWm)

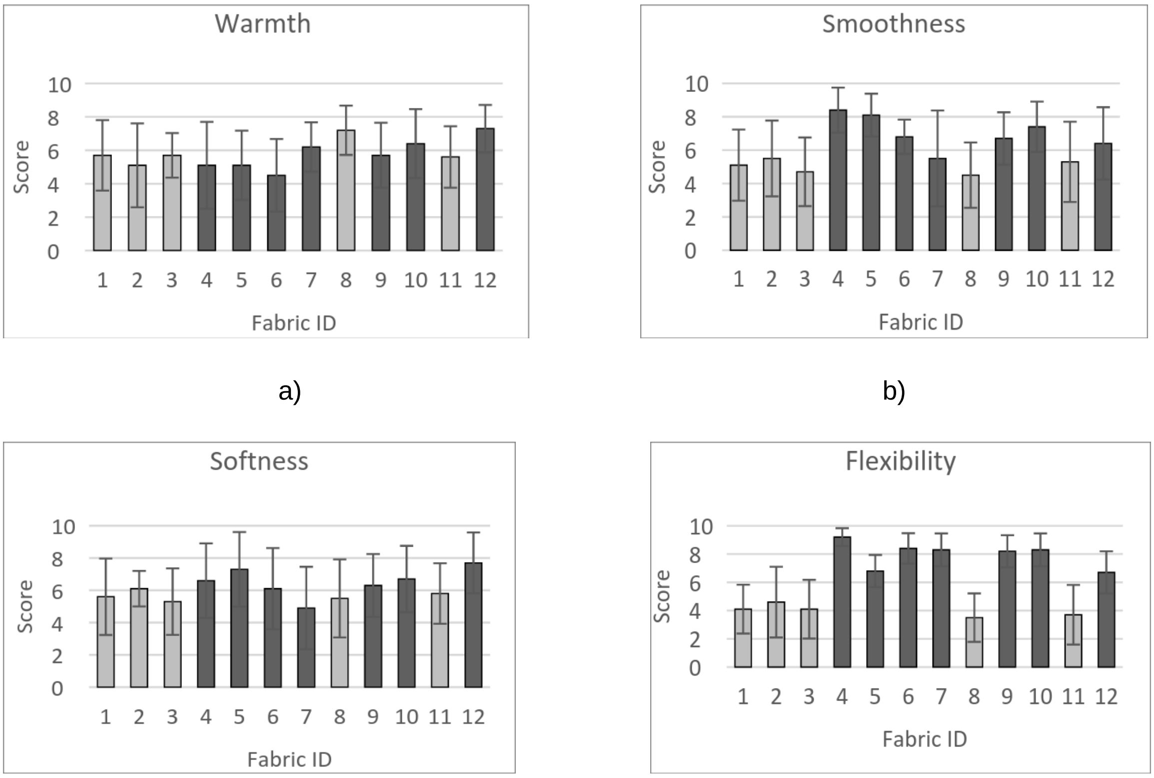
As shown in Table 4, softener concentration (Soft) has also a statistically significant influence (linear or quadratic) on almost all indices, but this influence is less pronounced than mass per unit area (m). The fiber composition of the upper layer has a statistically significant influence on several FTT fabric indices such as bending average rigidity in wale direction (BARa), bending work (BWa, BWe, BWm), maximum thermal flux (Qmax), surface friction coefficients SFCm as well as on thermal conductivity during compression (TCC) and fabric thickness (T). For instance, the maximum thermal flux (Qmax) is higher in fabrics with yarns (CV) and these fabrics also have a higher average friction coefficient (SFCm).

As mass per unit area (m) is the dominant factor and its range is quite large (i.e. 185-560 g/m^2) we have also analyzed the five lightweight samples (i.e. ID 4, 6, 7, 9, 10) and five heavy samples (i.e. ID 1, 2, 3, 8, 11) independently, to determine if viscose fibers (CV) and softener level (Soft) have an important influence within each group. We found that CV and Soft only play a minor role for bending properties and a major role for the compression properties of the heavy fabrics. CV is important to explain the Qmax differences within the group. For the light fabrics, composition CV influences the surface friction coefficient SFC, and the softener concentration (Soft) influences the roughness amplitude SRA. At the same time, for the heavy fabrics, the mass per unit area (m) is dominant and

SRA changes are not related to composition or softener level. Mass has also a dominant effect on the roughness wavelength SRW but the heavy fabrics do show a dependence also on the concentration softener Soft. The thermal conductivity during compression (TCC) of both heavy and light fabrics is influenced by the composition (i.e. CV leads to higher TCC), while thermal conductivity measured during recovery (TCR) was not dependent on concentration and composition. These results correspond with the overall results shown in Table 4, where composition and softener concentration are mostly secondary effects in the models. The results indicate that the effects of composition and softener will depend on the mass per unit area of the fabric, and hence only come forward in a global model if the effect is likewise over the different weight groups or is sufficiently strong in a single group.

4.2 Fabric tactile properties assessed by panels

The mean values (M) and standard deviation (SD) of the scores given by ten assessors to the fabrics' warmth, softness, smoothness and flexibility can be seen in Figure 3, where the heaviest fabrics (ID 1, 2, 3, 8 and 11) are indicated by a lighter color. Due to the high number of fabrics evaluated, disagreements were noticed between respondents which is indicated by the large standard deviations bars. This is in agreement with previous research (Grinevičiũte, 2004), where 13 samples were ranked by panels and which recommended to limit the number of specimens to 10 or to use another evaluation method such as paired-comparison technique. The best consensus between the assessors was achieved for flexibility, while warmth of the fabrics was most difficult to assess.



a)

b)

c) d)

Figure 3 Mean scores and standard deviation given by assessors for a) warmth, b) smoothness, c) softness and d) flexibility of the fabrics ID 1-12

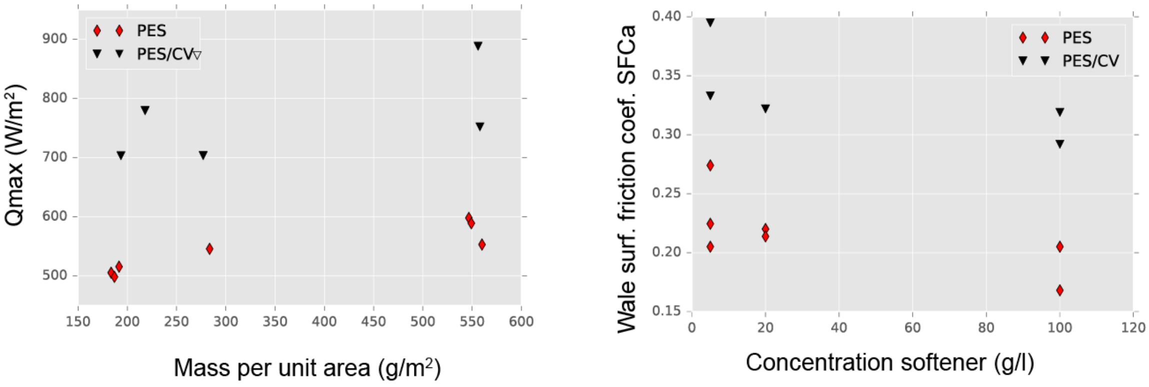
4.3 Influence of production parameters on selected tactile properties of the fabrics

The prediction models summarized in Table 5 highlight the influence of the three variables (i.e. mass per unit area (m), softener concentration (Soft) and viscose composition (CV) on four tactile properties of the fabrics assessed by panels. Stepwise regression was used, considering linear terms, quadratic terms and mixed terms. The complete panel dataset (individual scores given by ten assessors) was first used to create an overall model, after removing outliers in the grading outside the inter quartile range (IQR). Due to the high variance between the scores given by the assessors, (high STDEV, as shown in Figure 3), models with overall low R^2 adjusted values (0.05-0.65) were found as shown in Table 5. Nevertheless, the p-values<0.05 indicate that the considered productions parameters are significant predictors for the four tactile properties. Next, a second stepwise regression analysis was done, using only the average values of the scores given by the assessors, resulting in slightly different models with considerably higher R^2-values, as expected. The means are used here and presented as context, as models based on the means are needed in the following Section.

Table 5 Relationship between the tactile properties of the fabric and mass per unit area (m), concentration softener (Soft) and viscose composition (CV)

	Statistical model based on complete data set			Statistical model based on mean values of the data set		
	Model	R^2 adj	p-values	Model	R^2 adj	p-values
Softness	$-5.6.10^{-5}\ m^2 + 0.041\ m + 0.37$	0.08	<0.012	$-\ 5.8.\ 10^{-5}\ m^2 + 0.042\ m + 0.12$	0.54	<0.020
Flexibility	$-0.013\ m + 1.7.10^{-5}\ m.\ Soft + 10.8$	0.65	<0.040	$-0.012\ m + 10.67$	0.95	<0.001
Smoothness	$-8.10^{-6}\ m^2 + 1.06\ CV + 6.95$	0.23	<0.005	$-\ 8\ .10^{-6}\ m^2 + 1.06\ CV + 6.95$	0.73	<0.030
Warmth	$-0.87\ CV + 6.1$	0.05	<0.020	$-1.15\ CV - 0.008\ Soft + 6.629$	0.69	<0.030

Among the three selected variables, only mass (m) has a significant influence on the softness of the fabrics, but it is a rather poor predictor, as indicated by the low R^2-adjusted value. On the other hand, a good model was found for fabric flexibility which strongly depends on the fabric mass per unit area, while the overall model also detects an influence of the concentration softener. Though weak due to the variance in human grading, the statistical model in Table 5 suggests that viscose fabrics (CV) are smoother than the polyester fabrics and that smoothness of the fabrics with similar composition decreases when their mass per unit area (m) increases. A similar trend is also present in Figure 3b, which shows mean scores of smoothness of 7.4, 6.4 and 4.5 for polyester fabrics ID10, ID12 and ID 8 with mass per unit area of 185 g/m^2, 275 g/ m^2 and respectively 560 g/ m^2. To clarify this, the fabrics ID10, 12 and 8 were analyzed with a stereoscope Olympus SZX10 equipped with a software Cell^D. These three polyester fabrics were treated with a similar quantity of softener (5 g/l) and were differentiated only by their mass (m). The images in Figure 1 show a change in texture with the fabric mass per unit area (m). This was also indicated by the FTT that measured higher values for the surface roughness amplitude (SRA) for the heavier fabrics ID 1, 2, 3, 8, 11 as compared with the lightweight fabrics ID 4, 6, 7, 9 and 10 (see Table 3). This surface unevenness is a consequence of the production process of these double-layered knitted fabrics filled with BCF yarns. The negative influence of the mass (m) on smoothness should be therefore carefully interpreted and not extended to other type of fabrics with different architecture. Lastly, the mass per unit area seems to have no significant influence on fabric warmth. The statistical model suggests that viscose fabrics (i.e. ID 2, 4, 5, 6, 11) are cooler than the polyester fabrics and the model that consider the mean values also shows a small negative influence of the softener concentration on fabric warmth. The model that considers the complete dataset is particularly weak which is due to the high variance between the scores given by assessors who had difficulties to classify the fabrics according to their warmth. Despite the poor model, the trend found seems to be correct and in line with other research. For instance, viscose fabrics (PES/CV) were found smoother and exhibited a higher Qmax than polyester fabrics, as shown in Figure 4a. Viscose fabrics seems to have a higher friction coefficient (SFCa) than polyester fabrics, as shown by model in Table 4 ($SFCa= 0.12\ CV – 2.2\ .10^{-3}\ Soft + 1.6.10^{-5}\ Soft^2 + 0.25$). The additional moderate, negative influence of the softener concentration on SFCa can be also seen in Figure 4b. This is in line with other research (Vivekanadan, 2011) that showed an increase of Qmax with the increase in smoothness of fabric surface. A KES-F equipment was used in that study to assess several fabric indices and showed that denim fabrics washed several times become smoother and feel cooler due to a higher Qmax. They also claim that successive washings reduce the surface roughness and lead to an increase of the friction coefficient. We have also analyzed the light and heavy fabrics separately. Within the group of heavy fabrics, only the mass per unit area (m) of the fabric had a significant influence on its warmth. Nevertheless, for the light fabrics, a similar model as the one shown in Table 5 can be constructed which shows that viscose fabrics feels cooler and also that more softener leads to cooler fabrics.



a) b)

Figure 4 Viscose fabrics (PES/CV) have a higher Qmax (a) and friction coefficient SFC (b) than polyester fabrics (PES)

4.4 Influence of FTT fabric indices on selected tactile properties of the fabrics

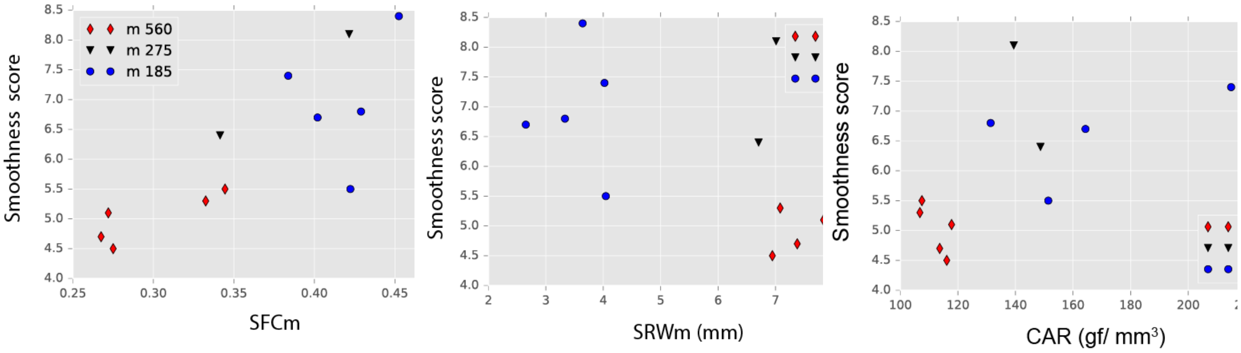
We constructed prediction models for the tactile properties based on the FTT fabric indices. In case of those fabric properties (i.e. bending, roughness, friction) evaluated in two directions, we considered the average values (m) for the wale and course directions and included only properties that significantly increase the R^2 value of the model. As the set of samples used for objective and subjective assessment is not identical, we have correlated the mean values of FTT fabric indices with the mean values of the scores given by the ten assessors to the four tactile indices. The results of the stepwise regression are summarized in Table 6.

Table 6 Relationship between the tactile properties assessed by panels and FTT fabric indices

	Statistical model	R^2 adj	p-values
Softness	$-1.5.\ 10^{-4}$ BWm + 0.37 SRWm + 12.57 CRR + 0.23 TCR – 13.7	0.78	<0.041
Flexibility	1.91 T + 10.66	0.97	<0.001
Smoothness	15.9 SFCm + 0.04 CAR + 0.32 SRWm –0.03 RAR + 0.47	0.88	<0.034
Warmth	$-45.\ 10^{-4}$ Qmax + 8.66	0.39	<0.017

It was found that the bending work BW, compression recovery rate CRR, roughness wavelength SRW and thermal conductivity TCR have a significant influence on the fabric softness (R^2adj=0.78) and fabric flexibility could be fully predicted based upon the differences in thickness, and hence mass per unit area. A very strong statistical model (R^2adj=0.88) was obtained for smoothness which is positively influenced by the friction coefficient (SFCm), compression rigidity (CAR), roughness wavelength (SRWm) and negatively influenced by compression recovery average rigidity (RAR). Hu et al. (2006) evaluated various fabrics for clothing and found that compression properties (i.e. compression force

FCmean) account for 69.5% and 77% of the variance in smoothness and softness, respectively. The increase of SFCm leading to smoother fabrics (see Figure 5 a) is somehow unexpected but is however consistent with our findings in chapter 4.3 and other research (Vivekanadan, 2011). As shown in Figure 1, the heavy fabrics have more texture, which reduces the contact surface between the FTT friction test element and the fabric and hence lower SFC is measured. The texture variation with the fabric mass per unit area leads also to higher roughness SRWm and lower CAR and may justify why the panel evaluates the heavier fabrics less smooth (see Figures 5b, 5c).



a)

b)

c)

Figure 5 Lightweight fabrics (m 185) exhibits high friction coefficient SFC$_{m}$ (a), low roughness SRWm (b) and high CAR (c) are evaluated as smoother than the heavy fabrics (m 560)

In the model constructed, SRWm acts as a correction term, with SCFm as primary variable, explaining the positive sign of the SRWm coefficient. This shows that focusing only on friction coefficients to evaluate smoothness is not correct. A lower SFCm leads to a smoother fabric only if the other properties of the fabric (i.e. roughness), can be kept constant, which is not the case for the considered mattress ticking fabrics. Concerning the FTT and the used friction plates to measure friction, the SFCm can only be used as a direct predictor for smoothness if the fabrics used have sufficiently smooth surfaces. This is not the case of our fabrics, therefore we constructed a smoothness model excluding SFCm. The model obtained via stepwise regression (Smoothness = -1.86.10^{-4} BWm + 3.54.10^{-3} Qmax +0.02 CAR + 0.19 TCR – 6.89) is slightly better (R^{2}adj=0.89) than the original model, though the first terms have slightly worse p-values than the original model. This model shows the same CAR-dependency, while friction and roughness terms have been replaced by bending work and thermal variables. The thermal input corresponds with cooler fabrics feeling smoother, while increasing bending work also lead to less smooth fabrics. The warmth of the fabrics could not be modelled well with the FTT fabric indices. A weak relation with Qmax is obtained (R^{2}adj=0.39), with warmer fabrics having lower Qmax as expected, but this is not sufficient to explain the panel results. It seems that FTT does not measure sufficient parameters to grasp the full warmth feeling of humans on touch or the human variation in grading is too large to obtain good models based on 10 assessors. The model can be improved (R^{2}adj=0.713) by considering mixed terms and quadratic terms (i.e. warmth= -0.016

SFCm*Qmax – 0.43 T^2 + 0.002 TCC * TCR), but at the cost of on overly complex model.

5. Conclusions

In this study the influence of three production settings on the fabric hand assessed by FTT and four tactile properties assessed by expert panels was investigated. Among the selected variables, fabric mass per unit area has the largest influence on all FTT fabric indices. Considerable variances were observed between the scores assigned by the panel due to subjective perception of assessors and probably also due to the large fabric set. That resulted in poor correlations between tactile properties and selected production parameters, although the trends seems to be correct and all the factors were found statistically significant.

This study shows once again the complexity of the fabric hand assessment both by human subjects and instruments. Correct subjective assessment is particularly complex in case of a high number of fabrics with special textures. Nevertheless strong correlations were found between the FTT fabric indices and tactile properties assessed by the panels, except warmth. The results are promising and show the potential of FTT to assess mattress ticking fabrics, with elevated mass per unit area and uneven texture and also its ability to distinguish between such fabrics differentiated by several production parameters. Nevertheless further research should be conducted to confirm these results and build statistical models dedicated to this type of fabrics to predict their primary and global comfort indices.

In our study the fabric mass per unit area is varied within a large range and therefore this parameter was identified as most significant among all three variables considered. Further studies should narrow this range to correctly identify contribution of other factors like fibers, softener concentration, etc. Also the size of the fabric set should be reduced to allow more accurate subjective evaluation. These findings are relevant to stakeholders of mattress ticking fabrics. Previous research payed limited attention to sensorial comfort of mattress ticking fabrics, although enhanced fabric hand seems to be demanded more and more by customers. The results suggest how selected production parameters may be tuned to enable price-efficient engineering of fabrics with enhanced tactile properties. Changes of fabric hand due to production settings were clearly quantified by FTT, an instrument that was previously mainly employed for clothing fabrics.

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