AN INVESTIGATION OF FABRIC PROPERTIES AND NEEDLE PENETRATION FORCE DURING TAILORING

DİKİM ESNASINDA OLUŞAN İĞNE BATIŞ KUVVETİ VE KUMAŞ ÖZELLİKLERININ İNCELENMESİ

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ABSTRACT

Fabrics are the raw material used in clothing production and vary in weave structure, weight, yarn properties, tensile strength and physical-mechanical properties. Together with sewing parameters, fabric properties determine seam quality. Needle penetration force is a dynamic phenomenon and represents quantitative measure of the fabric damage, where a high value of needle penetration force is associated with high risk of fabric damage. In the present study woven fabrics used for tailoring jackets and blazers, were analyzed regarding their physico-mechanical and physical-mechanical properties using the FAST system. Needle penetration force was measured on the ITV measuring system. The aim of the study was first to examine the fabric properties of two basic weave patterns and to discover needle penetration forces based on the selected needle shape and size that could be used in commercial tailorability process. Then, factor analytic technique was used to detect structure between tested variables. The three independent extracted factors were assigned as needle penetration force, physical and mechanical fabric properties and fabric density. Results shoewed that fabric weight and strenght has influence on needle penetration force, whereas physical-mechanical properties, except from extensibility do not have an influence.

Keywords: Woven fabrics, fabric weight, FAST system, physical and mechanical fabric properties, needle penetration force

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1. INTRODUCTION

Fabrics are the raw material used in tailoring and vary based on fabric quality, weave structure, fabric weight etc. Fabric quality is characterized by its mechanical properties, therefore fabric properties directly affect the material behavior during the garment manufacturing process. Textile materials (fibers, yarns and fabrics) are in the process of manufacturing and later during use stressed in various ways as: compressive, tensile, shear, bending and torsion (1). Therefore, fabric properties and sewing parameters are essential parts in determining the seam quality. Good handle, garment comfort and appearance are the main three criteria for the objective evaluation of garment performance. The Csiro Division of Wool Technology developed in the 1980s the Fabric Assurance by Simple testing (FAST) system for the fabric objective measurement (FOM) (2). The FAST system consists of three measuring instruments: FAST-1 (compression meter), FAST-2 (bending meter), FAST-3 (extension meter) and FAST-4, a test method for testing the fabric dimensional stability. The FAST system measures fabric mechanical properties at low-stress level loads, which respond to real wearing conditions. Fabric properties determined by the FAST system are plotted on the control chart and if they fall into the gray zone they are and used by tailors to highlight problems that may be encountered in garment production. Fabric properties that fall into the grey zone are associated with problems in garment making and thus are used for diagnosis and corrective action (3-7). Various studies have assessed the interrelation of mechanical and physical fabric properties on the seam and clothing quality, appearance, tailorability and performance, therefore sewing parameters and fabric properties play important roles in determining the seam quality (2, 8 – 13). During the stitch formation, the sewing needle cause sewing damage to the fabric. The study of needle penetration force dates back to the year 1936 where sewing damage of woven fabrics were assigned to yarn friction in the fabric and yarn to steel friction caused by needle penetration. Thus the relationship between needle penetration force, seam and fabric damage has already been illuminated. The literature reported about two kinds of sewing damages. The first one was damage caused by needle heating when using thermoplastic synthetic fabrics and has already been well understood. The opposite was the needle penetration force that cause mechanical damage on a given fabric. Due to the fact that needle penetration force is unique dynamic phenomenon related to the used sewing machine, needle penetration force should be measured using sensors build into the used sewing machine. The Institute for Textile Research at Denkendorf, Germany developed a system to measure needle penetration force and was used in this study (14-17). The widespread use of high speed sewing machines in the manufacturing process assist the analysis of needle temperature caused by the thread friction and fast needle moving during sewing (18). Dal et al. also reported that sewing needle coatings effects the needle temperature during sewing and is therefore a factor that can improve sewing quality and performance (19). The research addresses the relation of fabric properties of two basic weave patterns and needle penetration forces based on the selected needle shape and size that are used in commercial tailorability process. Factor analysis was used to identify and describe the relationship among the tested variables. The purpose of the study was to test the designed woven fabrics from a Croatian manufacturer which are used for tailoring jackets and blazers, to discuss fabric mechanical properties in the context of their performance during tailoring in order to improve the apparel making-up process.

2. EXPERIMENTAL

Four different fabric samples were used in the analysis. These fabrics were made in a Croatian fabric manufacturing company and are suitable for producing apparel such as mens jackets and blazers.

The samples were labelled Sample I to Sample IV for identification. The samples were tested for their physical and mechanical properties using the SiroFAST system, Figure 1. Prior to the FOM testing the samples were left in standard conditions (realtive humidity 65±2% and temperature 20 ± 2°C) which ensured the reproducibility of results. The basic fabric parameters such as mechanical fabric properties were tested on the Statimat M tensile tester made by Textechno in accordance with the standard EN ISO 1421:1998.

To measure needle penetration force, a lockstitch sewing machine Pfaff 483 to produce stitch type 301 (ISO 4915) was used for the analysis. The measuring system consisted of a sewing machine with a strain gauged needle plait around the needle hole connected to the Wheatstone bridge, Figure 2. The registered signals of the sewing needle penetration force were converted from analog to digital via DMCplus measurement amplifier and sent to the personal computer with the ITVSMP software package, (16,17).

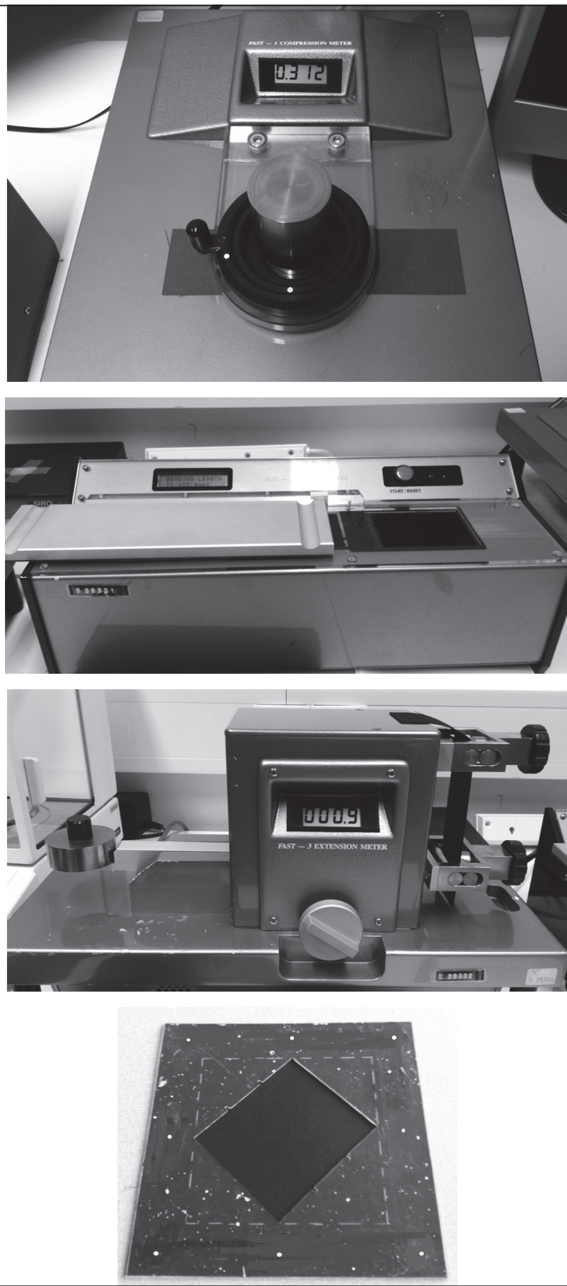


Figure 1. SiroFAST system instruments (taken by the authors)

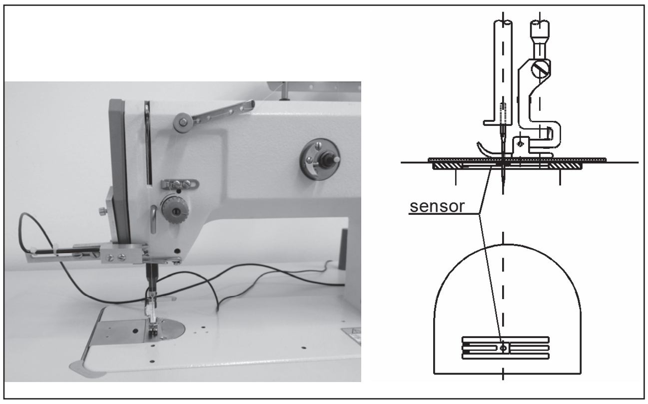


Figure 2. Measuring device to measure needle penetration force (taken by the authors)

The process of sewing was carried out using a Schmetz round point needle with a medium needle size of Nm 90 and under conditions of 23.5°C and 50.0% relative humidity. All samples were tested by sewing 2 layers of the same fabric at sewing speed of 2000 rpm along the warp direction. In order to get a constant sewing machine speed the first and last 10 stiches were removed from the analysis. To measure only needle penetration force, sewing thread was also removed.

3. RESULTS AND DISCUSSION

3.1. Tensile strength

The testing results of the fabric samples suitable for producing apparel such as mens jackets and blazers are presented in Tables 1, 2, 3 and Figures 3, 4 and 5.

Fabric Samples I, II and IV were woven in plain weave (45% wool, 55% polyester for Sample I and II, and 44% wool, 54% polyester and 2% elastane fibre for Sample IV) with the yarn count (25x2) for Sample I and II, and yarn count 33 for Sample IV, while Sample III was woven in twill weave 2/2 (44% wool, 54% polyester) with the yarn count of 33. Since samples I and II do not differ in the yarn type and fineness with smaller deviations in density and weight, the breaking force does not differ much (warp: 714.2/729.7 N, weft: 609.6/611.2 N), as well as the elongation at break (warp: 31.7/36.9%, weft: 30.1/31.2%). Sample III has a higher breaking force than the first two samples (warp: 1100.1 N, weft: 853.4 N), as well as the elongation at break (warp: 51.5%, weft: 46.6%). Sample IV differing in density, but not in raw material and fineness has the lowest breaking force (warp: 509.9 N, weft: 438.4 N), but the elongation at break in the weft direction is greater (warp: 29.4%, weft: 45,6%). Breaking force is directly fabric density-dependend. Thus, the breaking force is higher if a fabric has a higher density in warp and weft direction with the exception of Sample IV were breaking force and elongation at break have the lowest measured values and can be explained by the elastane fibre in the yarn.

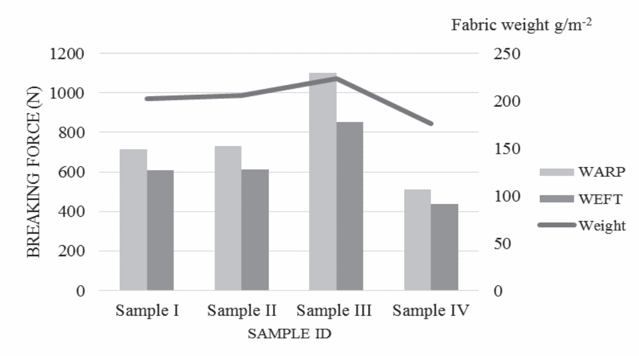
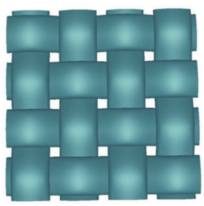
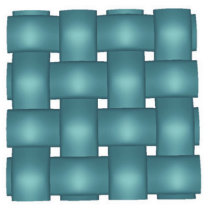
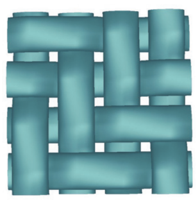
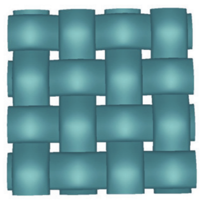


Figure 3. Breaking forces and fabric weight

Table 1. Basic sample parameters

		Sample I		Sample II		Sample III		Sample IV	
		Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
Raw material composition		45% wool 55% polyester		45% wool 55% polyester		45% wool 55% polyester		44% wool 54% polyester 2% elastane	
Fineness of warp and weft yarn (tex)		25×2		25×2		25×2		33	
Fabric weight (g/m^2)		202		206		223		176	
Density of warp and weft (threads/1 cm)		18.7	17.6	19.6	18.7	28	22	26.3	22.5
Weave		Plain weave 		Plain weave 		Twill weave 2/2 		Plain weave 	
Colour		Light blue		Blue		Black		Black	
Breaking force of the fabric (N)	$\bar{x}$ (N)	714.2	609.6	729.7	611.2	1100.1	853.4	509.9	438.4
	CV (%)	3.06	0.89	2.54	2.53	1.91	2.24	2.71	4.95
Elongation at break of the fabric (%)	$\bar{x}$ (N)	31.7	30.1	36.9	31.2	51.5	46.6	29.4	45.6
	CV (%)	2.46	2.82	2.15	3.72	2.08	3.53	2.53	1.92

The fabric tensile strength in warp direction is higher than the weft for all samples. It is related to the weight of the fabrics, if the weight is higher the tensile strength increase. The sample III is made in twill weave and has a breaking load difference of 247 N between warp and weft.

3.2. Physical and mechanical properties of fabrics

The average thickness of the fabric (T_2 and T_{100}) at loads (196 Nm^{-2} and 9.81 kNm^{-2}) differs among the samples. At the first load the average thickness ranges from 0.425 mm (Sample I) to 0.578 mm (Sample IV), and at the second load it ranges from 0.316 mm (Sample I) to 0.448 mm (Sample III), Table 2. At both loads Sample I has the minimum thickness which was to be expected because it is woven in plain weave with the lowest density, while Sample III woven in twill weave with the highest density and weight had the greatest thickness.

The surface thickness of the fabric (ST) was obtained by the difference in the thickness of the fabric obtained at the above-mentioned loads and ranges from 0.107 mm (Sample II) to 0.192 mm (Sample IV), Table 2.

The average released thickness of the fabrics (T_{2R}, T_{100R}) at different loads (196 Nm^{-2} and 9.81 kNm^{-2}) differ by samples too. At the first load the average released thickness ranges from 0.425 mm (Sample I) to 0.578 mm (Sample III), and at the second load from 0.316 mm (Sample I) to 0.448 mm (Sample III). Sample I has the lowest released thickness at both loads, while at a lower load Sample IV has the maximum thickness, and Sample III at a higher load. The released thickness of surface fabric layer (SRT) is the lowest (0.118 mm) for Samples I and IV, and the highest (0.139 mm) for Sample III.

Bending length ($c_{1,2}$) differs by samples (Table 2, Figure 4). Samples I and II do not differ in yarn, weave and only slightly in density in the warp and weft direction, but the bending length differ in the warp (22.3/14.2 mm) and weft direction (21.8/14.5 mm). Sample IV (14.2/9.3 mm) woven with 2% of elastane fibers has the shortest bending length, whereas Sample I has the greatest bending length (22.3/21.8 mm). Sample III woven in twill weave has a bending length of 17.2/14.2 mm in warp and weft direction.

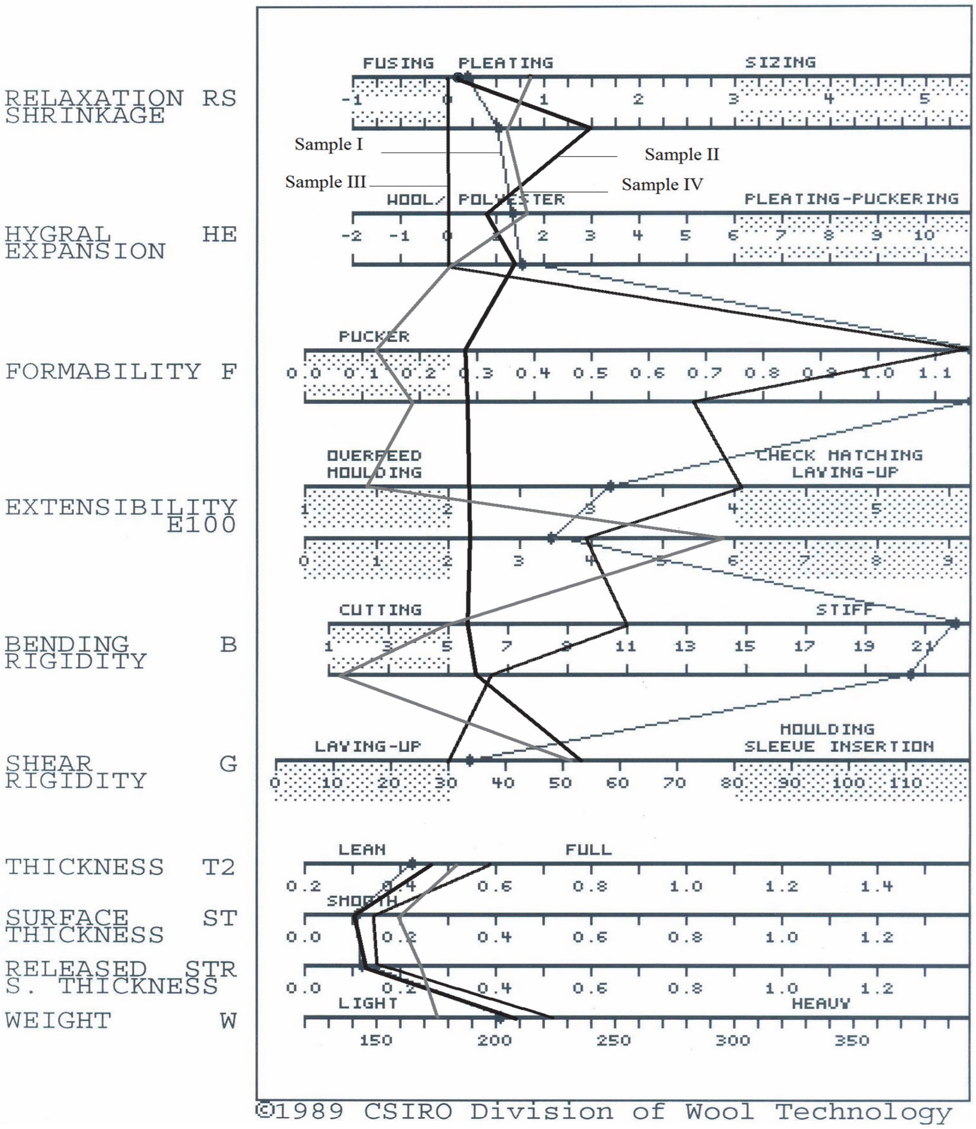


Figure 4. The FAST control chart for tested fabrics

Bending rigidity (B_1, B_2) differs by samples; the values of Sample I are considerably higher in comparison to the other samples (22.0/20.6 μNm), followed by Sample III (11.1/6.3 μNm), Table 2, Figure 4. Sample IV woven in plain weave as Samples I and II with elastane fibers in the yarn has the lowest values (5.0/1.4 μNm), while the sample woven in twill weave has higher bending rigidity (11.1/6.3 μNm) when comparing to Sample II and IV. Sample I and II are both woven in plain weave and have similar sample parameters (Table I), but have considerably different fabric properties. The quite drastic change in fabric properties can be explained due to the application of certain dying and finishing agents and processes.

The greatest extensibility of the fabric in the warp and weft expansion (ε_{100-1}) is observed in Sample III (4.1/3.9%) probably influenced by the weave pattern. At lower loads (ε_{5-1} do ε_{20-2}) the values of extensibility for all three samples are relatively low in the warp and weft direction.

The greatest formability is observed in Sample I (1.96/1.81 mm^2), while Sample IV has the lowest formability (0.11/0.18 mm^2).

Shear rigidity (Nm^{-1}) is the greatest in Sample II (52 Nm^{-1}) woven in plain weave with a slightly greater density than in Sample I (34 Nm^{-1}), but according to the results of shear rigidity they differ substantially (Table 2). The difference in shear rigidity between Samples I and II is probably influenced by the fabric dyeing process, since the fabrics have different colours. Fabric dyeing and finishing effect fabric properties such as shear rigidity and bending thus change fabric handle and tailorability (20).

The measurement results of relaxation shrinkage are expressed in the values of relaxation shrinkage (RS-1 and RS-2), ranging from 0.1 for Sample II in the warp direction to 0.9 in Sample IV, (Table 2). Hygral expansion (HE-1 and HE-2) are expressed in values from 0.0 for Sample IV in weft direction to 1.6 for Sample I and II in weft direction. Sample III had the greatest fabric weight (g/m^2) of 223 gm^{-2}, while the lowest fabric weight had Sample IV of 176 gm^{-2}.

Table 2. Measurement results of physical and mechanical properties using FAST system

Instrument and test	**Kind of parameter**	**Mark/Unit**	**Direction**	**Fabric code**			
				Sample I	**Sample II**	**Sample III**	**Sample IV**
FAST-1	Thickness	T_2/mm	–	0.425	0.467	0.578	0.534
		T_{100}/mm	–	0.316	0.359	0.448	0.342
	Surface thickness	ST/mm	–	0.109	0.107	0.130	0.192
	Thickness	T_{2R}/mm	–	0.435	0.492	0.586	0.600
		T_{100R}/mm	–	0.318	0.361	0.447	0.353
	Released surface thickness	SRT	–	0.118	0.131	0.139	0.247
FAST-2	Bending length	c_1/mm	Warp	22.3	14.2	17.2	14.2
		c_2/mm	Weft	21.8	14.5	14.2	9.3
	Bending rigidity	B_1/mNm	Warp	22.0	5.7	11.1	5.0
		B_2/mNm	Weft	20.6	6.2	6.3	1.4
FAST-3	Extensibility	ε_{5-1}/%	Warp	0.1	0.0	0.1	0.0
		ε_{5-2}/%	Weft	0.0	0.0	0.1	0.1
		ε_{20-1}/%	Warp	1.4	0.8	1.8	0.3
		ε_{20-2}/%	Weft	1.3	0.7	1.6	2.0
		ε_{100-1}/%	Warp	3.1	2.2	4.1	1.5
		ε_{100-2}/%	Weft	3.4	2.3	3.9	5.8
		ε_{B5}/%	–	3.7	2.3	4.2	2.4
	Shear rigidity	G/Nm^{-1}	–	34	52	30	51
FAST-2 and 3	Formability	F_1/mm^2	Warp	1.96	0.29	1.28	0.11
		F_2/mm^2	Weft	1.81	0.30	0.68	0.18
FAST-4	Relaxation shrinkage	RS-1/%	Warp	0.2	0.1	–	0.9
		RS-2/%	Weft	0.5	1.5	–	0.7
	Hygral expansion	HE-1/%	Warp	1.3	0.8	–	1.6
		HE-2/%	Weft	1.6	1.6	–	0.0
Fabric weight		W/gm^{-2}	–	202	206	223	176

3.3. Needle penetration force

The test results for needle penetration force are presented in Table 4. The statistical analysis of needle penetration force for each Sample was based on 350 stitches from 5 measurements. The mean value of needle penetration force for Sample I was 456.4 (cN), for a min value 135.6 (cN), max value of 1183.0 (cN), coefficient of variation of 78.7 (cN) and standard deviation of 189.5 (cN). The Sample II has a mean value of 533.8 (cN), min value of 180.0 (cN), max value of 1412.7 (cN), coefficient of variation of 95.4 (cN) and standard deviation of 225.7 (cN). The Sample III has a mean value of 834.8 (cN), min value of 335.0 (cN), max value of 1926.1 (cN), coefficient of variation of 75.5 (cN) and standard deviation of 251.07 (cN). The Sample IV has a mean value of 268.7 (cN), min value of 130.9 (cN), max value of 640.0 (cN), coefficient of variation of 39.1 (cN) and standard deviation of 102.5 (cN). The lowest value of needle penetration force of 130.9 (cN) was recorded by Sample IV, where the maximum value for needle penetration force of 1926.1 (cN) was measured by Sample III. Sample I has a difference of the min and max values of needle penetration force of 1047.1 (cN), while the difference in Sample II was 1232.7 (cN). The highest value of the difference of min and max needle penetration force has Sample III was 1577.0 (cN), while the lowest value was calculated for Sample IV and was 509.1 (cN). The analysis of variance (ANOVA) were applied to test the difference between groups for the minimum needle penetration force ($p \leq 002$), maximum needle penetration force ($p \leq 000$), mean values of needle penetration force ($p \leq 000$) Table 3, and the influence of fabric density of warp ($p \leq 000$), and weft direction ($p \leq 000$). Sample IV has the lowest coefficient of variation, or the difference between the measured needle penetration forces. Extensibility of elastane fibre and single textured yarn affect needle penetration force balance. Sample III has the highest fabric weight, woven in twill weave, has the highest density in warp direction and has the highest values of needle penetration force. Sample I and II woven in plain weave have similar fabric weight and density in warp and weft, thus have similar values of needle penetration force.

Table 3. Analysis of variance of needle penetration force mean values

Source of Variation	*SS*	*df*	*MS*	*F*	*Significance*
Between Groups	831820,4	3	277273,5	124,4886	0,000
Within Groups	35636,79	16	2227,299		
Total	867457,2	19			

Table 4. Needle penetration force values of tested samples

Sample	Mean (cN)	Min (cN)	Max (cN)	Var (CoV)	Std dev (cN)
Sample I	462.7	214.4	1096.9	101.4	216.7
Sample I	461.4	180.8	1183.0	83.5	196.3
Sample I	448.4	190.7	863.0	57.1	160.0
Sample I	525.1	219.1	940.2	60.6	178.4
Sample I	384.3	135.6	985.7	69.2	163.1
MEAN	456.4	188.1	1013.8	74.4	182.9
Sample II	571.9	180.0	1412.7	135.8	278.7
Sample II	611.4	196.9	1157.2	86.0	229.3
Sample II	509.5	190.5	1046.9	71.1	190.3
Sample II	486.7	204.5	1081.1	81.6	199.3
Sample II	489.7	227.4	1041.7	74.1	190.5
MEAN	533.8	199.8	1147.9	89.7	217.9
Sample III	874.0	488.4	1508.7	53.5	216.2
Sample III	909.2	408.7	1926.1	164.2	386.4
Sample III	821.8	382.2	1227.6	31.7	161.4
Sample III	778.0	335.0	1269.5	54.0	204.9
Sample III	790.9	451.8	1166.8	48.8	196.4
MEAN	834.8	413.2	1419.7	70.4	233.1
Sample IV	281.3	138.6	625.8	34.4	98.3
Sample IV	269.3	141.1	606.7	33.4	94.9
Sample IV	242.6	130.9	616.9	37.5	95.4
Sample IV	272.5	134.1	640.0	51.1	118.0
Sample IV	278.1	130.9	532.4	35.5	99.4
MEAN	268.7	135.1	604.3	38.4	101.2

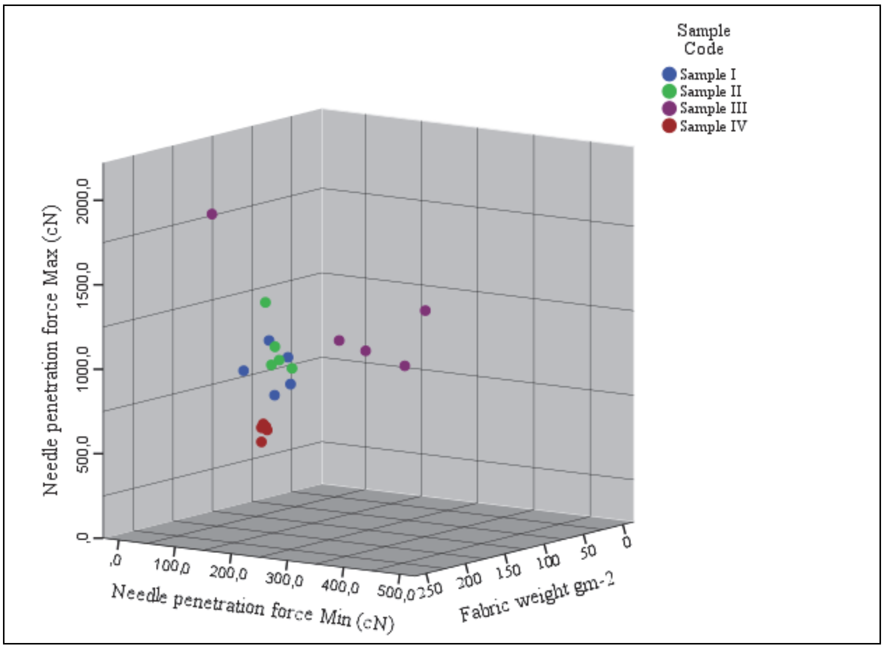


Figure 5. 3D scatterplot of needle penetration signal and fabric weight

Figure 3 shows the variation of the minimum and maximum values of needle penetration force for all tested samples according to fabric weight. From the figure can be concluded that while the fabric weight were increased, the needle penetration force were also increased.

The literature (9) report that formability (F), extensibility at 100 g cm^{-1} (E100) bending rigidity (B) and shear rigidity (G) are the mechanical properties that can have an infuence on fabric performance when tailoring cloths, so only those properties are used in the factor analysis. Due to the given result that fabric weight influence higher values of needle penetration force, fabric thicknes, and density in warp and weft direction were also used. The factor loadings correspond to the correlation between component (factor) and variable and provides information about the relation among variables, but still independent of one another. The variables used in the factor analysis is given in the Table 5.

A total of 15 factors were involved in the analysis. Table 6 displays the rotated component matrix with loadings for each factor.

Table 5. Correlation Matrix

	Correlation Matrixa,b														
Correlation	Formability (warp)	Formability (weft)	Extensibility at 100g cm^{-1} (warp)	Extensibility at 100g cm^{-1} (weft)	Bending rigidity (warp)	Bending rigidity (weft)	Shear rigidity	Fabric thickness during load T_2	Fabric thickness during load T_{100}	Fabric weight	Fabric strength (warp)	Fabric strength (weft)	Needle penetration force	Fabric density (warp)	Fabric density (weft)
Formability (warp)	1	0.941	0.752	-0.276	0.961	0.878	-0.885	-0.608	-0.821	-0.571	0.463	0.509	0.395	-0.262	-0.472
Formability (weft)	0.941	1	0.492	-0.275	0.997	0.976	-0.683	-0.733	-0.743	-0.276	0.153	0.211	0.091	-0.503	-0.653
Extensibility at 100g cm^{-1} (warp)	0.752	0.492	1	-0.339	0.542	0.407	-0.925	-0.259	-0.767	-0.968	0.93	0.943	0.891	0.19	-0.065
Extensibility at 100g cm^{-1} (weft)	-0.276	-0.275	-0.339	1	-0.245	-0.435	0.089	0.798	0.764	0.393	-0.374	-0.433	-0.452	0.676	0.761
Bending rigidity (warp)	0.961	0.997	0.542	-0.245	1	0.959	-0.734	-0.694	-0.746	-0.327	0.206	0.26	0.138	-0.44	-0.601
Bending rigidity (weft)	0.878	0.976	0.407	-0.435	0.959	1	-0.554	-0.86	-0.784	-0.209	0.088	0.157	0.049	-0.674	-0.802
Shear rigidity	-0.885	-0.683	-0.925	0.089	-0.734	-0.554	1	0.237	0.686	0.808	-0.739	-0.753	-0.661	-0.19	0.054
Fabric thickness during load T_2	-0.608	-0.733	-0.259	0.798	-0.694	-0.86	0.237	1	0.816	0.157	-0.07	-0.149	-0.095	0.899	0.981
Fabric thickness during load T_{100}	-0.821	-0.743	-0.767	0.764	-0.746	-0.784	0.686	0.816	1	0.694	-0.62	-0.679	-0.619	0.483	0.688
Fabric weight	-0.571	-0.276	-0.968	0.393	-0.327	-0.209	0.808	0.157	0.694	1	-0.992	-0.996	-0.976	-0.271	-0.032
Fabric strength (warp)	0.463	0.153	0.93	-0.374	0.206	0.088	-0.739	-0.07	-0.62	-0.992	1	0.997	0.993	0.34	0.113
Fabric strength (weft)	0.509	0.211	0.943	-0.433	0.26	0.157	-0.753	-0.149	-0.679	-0.996	0.997	1	0.991	0.266	0.034
Needle penetration force	0.395	0.091	0.891	-0.452	0.138	0.049	-0.661	-0.095	-0.619	-0.976	0.993	0.991	1	0.293	0.078
Fabric density (warp)	-0.262	-0.503	0.19	0.676	-0.44	-0.674	-0.19	0.899	0.483	-0.271	0.34	0.266	0.293	1	0.967
Fabric density (weft)	-0.472	-0.653	-0.065	0.761	-0.601	-0.802	0.054	0.981	0.688	-0.032	0.113	0.034	0.078	0.967	1

a Determinant = .000

b This matrix is not positive definite.

Table 6. Rotated Component Matrix[a]

	Component		
	1	2	3
Needle penetration force	.998		
Fabric strength (warp)	.996		
Fabric strength (weft)	.992		
Fabric weight	-.979		
Extensibility at 100g cm^{-1} (warp)	.898		
Bending rigidity (warp)		.953	
Formability (weft)		.942	
Formability (warp)		.899	
Bending rigidity (weft)		.855	
Shear rigidity		-.718	
Extensibility at 100g cm^{-1} (weft)			.914
Fabric density (weft)			.913
Fabric density (warp)			.906
Fabric thickness during load T_2			.881
Fabric thickness during load T_{100}			.610

The variables are grouped into three components. Component 1 has high loadings in the variables: needle peentration force, tensile strenght in warp and weft direction, fabric weight and extensibility in warp direction and are associated with the factor length with 56 % of variance. Component 2 has high loadings in variables bending rigidity and formability in warp and weft direction, and shear rigidity with 32 % of variance while component 3 has high loadings in extensibility in weft direction, fabric density in warp and weft direction and fabric thicknes with 12 %. The three identified factors were described by needle penetration force (Factor 1), physical and mechanical properties (Factor 2) and fabric density (Factor 3).

4. CONCLUSION

Needle penetration force occurs during the sewing process and represents quantitative measure of the fabric damage, where a high value of needle penetration force is associated with high risk of fabric damage.

Samples were tested for tensile strength. All samples were stronger in warp direction when compared to weft direction. Furthermore the samples were analyzed using the FAST system, and Fast fabric properties were plotted on the FAST tailoring control chart. The control chart has been established to show regions where the fabric properties can cause problems in the process of garment making. If the measured values fall into the shaded areas of the chart (Figure 2) there is an direct indicator of the likelihood of problems occurring either during or after the making-up process, while if the measured values fall into the non-shaded values, the fabric will be easily tailored. The Sample I and Sample III have high formability values, higher than 1.0 for both warp and weft directions and are in the non-control zone. High formability values give the fabric ability to absorb compression in its own plane without seam pucker. The Sample II has formability values in both directions slightly higher than 0.25 thus the values are in the non-control zone. The Sample IV has the lowest formability values that are lower than 0.25 and are in the control zone, thus the Sample IV has a high possibility of seam puckering, so likely to produce poor seam performance. The Sample I and II have extensibility values for both warp and weft directions under the non-control zone. Sample III has the has the extensibility values slightly higher than 4% where the Sample IV has the extensibility value in the warp direction under the control zone that can led to problems with overfeed seams and also molding problems. Samples I and II have bending and shear rigidity in the non-control zone. Sample III has values of the bending rigidity under the non-control zone, but the value of the shear rigidity is slightly below 30 N/m. Sample IV has the warp bending rigidity at the border in the control chart, and the bending rigidity in the weft direction is below 5 μN/m, but the Sample IV has good values of shear rigidity.

Sample I and Sample II have all FAST properties in the non-control zone makes the cloth manufacturing easy.

Sample III has low values of the shear rigidity which makes the fabric difficult to lay for cutting.

Sample IV has low values for formability, bending rigidity and extensibility in the warp direction that is related to the fabric weight and the fabric needs to be handled more carefully.

Sample IV had the lowest value of needle penetration force and the lowest fabric weight, while Sample II had highest value of needle penetration force and fabric weight. The results revealed that fabric weight has a significant influence on needle penetration force. Sample I and II have similar values and have almost the same fabric weight. Sample IV showed lowest value of variance while the Sample III showed highest value of variance. The variability could be affected by the weave pattern, fabric weight or cover factor and should be in the future analyzed in detail.

Sample I and Sample III have fabric properties that fall into the non-control zone, thus the fabrics have good quality which makes the process ability and tailoring easy and the fabric is suitable for tailoring. Sample III has fabric properties that require care in the process of cutting and sewing. When comparing fabric properties of tested fabrics, Sample IV has fabric properties that would cause the most difficulties and the fabric is predicted to cause problems during garment production.

The structure in the relationship between the tested variables were determined, where three independent extracted factors and assigned as needle penetration force, physical and mechanical fabric properties and fabric density.

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