

Structural effect of weft knitted pressure garments on applied pressure and thermal comfort properties

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This study aims at examining the effect of structural and process variables on thermal comfort properties of the compression garments produced with single-jersey weft knitted construction. The considered variables are elastane yarn count, elastane yarn tension during yarn positive feeding, reduction factor and fabric structure. To this end, 18 samples are manufactured according to Taguchi orthogonal array on a circular knitting machine. Heat transfer per cent, moisture transfer in the liquid phase and air permeability of the knitted fabrics have been measured and reported. The compression garments are sewn in cylindrical shape and the pressure applied on a cylinder is also measured by Kikuhime pressure sensor. The results demonstrate that the samples containing knit and miss stitches apply the highest amount of pressure and the sample having more tuck stitches represents the lowest pressure. Also, increasing the linear density of the elastic yarn and using a higher reduction factor provide a higher pressure. The results indicate that fabrics exerting greater pressure on the body have a tighter structure when stretched. Therefore, they show less air permeability, heat and moisture transfer. Also, for a certain fabric structure, an increase in reduction factor leads to open structure and creating more pressure. Consequently, air permeability and the heat and moisture transfer are increased. Samples which apply less pressure, are more permeable and transfer greater amount of heat, and moisture through their structure due to creation of an open structure in extended state.

Keywords: Air permeability, Comfort, Compression garment, Lycra, Moisture properties, Pressure therapy, Thermal properties, Weft knitted fabric

1 Introduction

Compression garments have elastic structures that are used to provide a certain amount of pressure on the human body¹. These clothings have attracted a lot of attention in the medical field. In addition to providing better treatment, they do not cause any other damage to the patient's body due to the lack of chemicals along with the disease cure. They are currently used for a wide range of applications such as sports clothing, compression stockings, anti-fatigue garments, compression bandage, etc².

Based on the application field, the applied pressure should be constant and uniform in different range. The pressure of less than 20 mmHg has been categorized as mild, 20–40 mmHg as medium, 40–60 mmHg as strong, and greater than 60 mmHg as very strong³. Several previous works have focused on the pressure exerted onto the body by different elastic weft and warp knitted fabrics containing elastane yarns⁴⁻⁹. Some researchers also tried to develop a analytical model for predicting the applied pressure

based on Laplace's equation as well as tensile characteristics of elastic fabric¹⁰⁻¹³. Also, with advances in 3D modelling technology, various 3D biomechanical models have been developed to simulate the garment-skin interface pressure using finite element modelling¹⁴⁻¹⁹. In addition to providing the required pressure by the pressure garments for various applications, their thermal comfort is also very important; because in some cases they must be used for a long time. Also, using the compression products during sport activities increases muscle temperature and the heat-load should be removed by human body to achieve the thermal balance. A successful pressure garment should transport heat, vapour and liquid sweat to the garment surface as fast as possible and help to control the body's thermal balance²⁰⁻²³.

The comfort characteristics of a weft knitted compression garments was evaluated in extended state by Gupta *et al.*¹¹. They concluded that, the fabric structure opens up in the extended state which makes the structure more permeable to air as well as water vapour. This also makes it more comfortable to wear in hot and humid conditions.

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Kumphai *et al.*¹² tested of six combinations of two-layer fabrics in terms of the thermal comfort. They reported that there was significant differences for both thermal resistance and air permeability between two-layer combinations. Sari and Oğlakcıoğlu¹⁰ produced various knitted structures by jacquard knitting technique. They examined the effect of channel size and quilted inlay design on the applied pressure as well as thermal and water vapour resistance. They concluded that an increase in the channel size leads to higher thermal and water vapour resistance.

Despite valuable experimental studies being conducted on the thermal comfort of compression garments, the effect of structural and process variables such as fabric structure, yarn tension, elastane yarn count and reduction factor on the thermal comfort characteristics has not investigated yet. To this end, this article provides an evaluation of thermal comfort properties in terms of air permeability, heat and moisture transfer. Eighteen elastic weft knitted samples are produced according to Taguchi method on a circular knitting machine. The compression garments are sewn in cylindrical shape and the pressure applied on a rigid cylinder with a determined diameter is also examined. Then the thermal comfort characteristics are evaluated in three different reduction factors.

2 Materials and Methods

2.1 Yarns

Elastic weft knitted fabrics were produced in single-jersey construction using Lycra- covered polyester yarns (100 denier) for loop formation. In addition to this yarn, two different bare Lycra filaments (140 and 500 denier) were inlaid through the fabric structure to improve width-wise extensibility and to obtain different levels of the applied pressure.

2.2 Taguchi Experimental Design

The experiments almost consist of several variables. Taguchi method is often applied in such cases to predict the optimum conditions and to determine the effect of each controllable factor on a particular response. The controllable factors considered in this study are fabric structure, elastane yarn count, feeding tension of elastane yarn and garment’s reduction factor. There are three controllable factors, and each one has three levels with the exception of elastane yarn count. The factor of elastane yarn count varies at two levels.

Accordingly, it is found that the appropriate orthogonal array is L18, which is demonstrated in Table 1.

2.3 Preparation of Fabric Samples

Knitted fabric samples were manufactured on a single-jersey circular knitting machine (Falmac, E24) equipped with positive yarn feeding. A feeder tension controller is utilized to apply a constant tension of 6, 10 and 14 cN on the elastane yarn.

Three different knitted samples were prepared in combination of knit, miss and tuck loops as shown in Fig. 1. The LCP yarns and BL filaments were introduced to the feeds which produced the odd courses (marked with green color) and even courses (marked with grey color) respectively.

For the first level of the fabric design (KMT sample), knit stitches were formed on all needles at first and third courses by feeding the Lycra-covered polyester filaments. Also, tuck loops were formed on even and odd needles at second and forth course respectively by feeding the bare Lycra yarn. For the second level of the fabric design (KT2M sample), knit and miss stitches were formed on even and odd needles respectively at first course by feeding the Lycra-covered polyester yarns. The same pattern is repeated at the second course by feeding the Lycra yarn. For the third course miss and knit stitches were formed on even and odd needles respectively by feeding the Lycra- covered polyester

Table 1 — Taguchi orthogonal array L18

Number	Elastane yarn count, den	Fabric structure	Elastane yarn tension, cN	Reduction factor, %
1	500	1	14	10
2	500	1	10	15
3	500	1	6	20
4	500	2	14	10
5	500	2	10	15
6	500	2	6	20
7	500	3	14	15
8	500	3	10	20
9	500	3	6	10
10	140	1	14	20
11	140	1	10	10
12	140	1	6	15
13	140	2	14	15
14	140	2	10	20
15	140	2	6	10
16	140	3	14	20
17	140	3	10	10
18	140	3	6	15

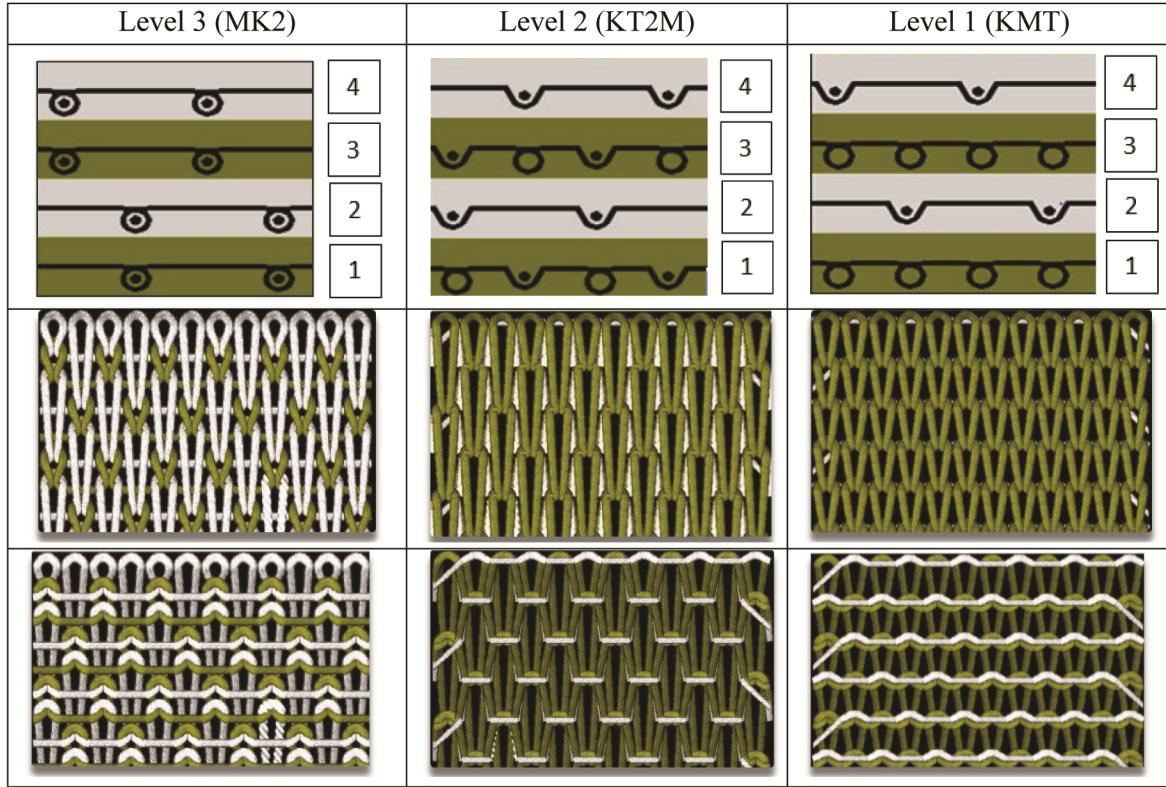


Fig. 1 — Notations of knitted fabrics

yarns. The same pattern is repeated again at the fourth course by feeding the bare Lycra yarn. For the third level of the fabric design (MK2 sample), knit and miss stitches were formed on even and odd needles respectively at first course by feeding the Lycra-covered polyester yarns. The same pattern is repeated at the second course by feeding the Lycra yarn. For the third course, miss and knit stitches were formed on even and odd needles respectively by feeding the Lycra-covered polyester yarns. The same pattern is repeated again at the fourth course by feeding the Lycra yarn.

2.3.1 Fabric Relaxation

Knitted fabric samples were fully relaxed before characterization to reduce the residual stress and remove any possible oils on the fabrics. The relaxation process was carried out according to AATCC 99 standard method. The produced samples were cut in determined dimensions for fabric characterization.

2.3.2 Interface Pressure Evaluation

Pressure applied on a cylindrical body is directly proportional to the reduction factor (RF), which is defined as follows ¹²:

$$R_f(\%) = \frac{\text{Cylinder diam.} - \text{Fabric tube diam.}}{\text{Cylinder diam.}} \times 100 \quad \dots(1)$$

In order to achieve certain amount of applied pressure, the reduction factor is usually chosen between 10 and 20% ¹⁰. As the reduction factor value increases, fabric stretchability also increases simultaneously.

In order to measure the applied pressure, each fabric tube was mounted on a rigid cylinder having dimension $7.79 \times 20 \times 0.2$ cm and the pressure at fabric-tube interface was recorded. Measuring process was carried out using a Kikuhime sensor supplied by TT Medi Trade, Denmark, having a pressure range of 0 to 120mmHg and error of ± 1 mmHg.

For measuring the pressure, the sensor was placed on the cylinder surface and then adjusted to a zero reading on sensor display. The fabric tube was mounted on the cylinder and then allowed to relax for 5 s before reading the applied pressure. The mean of 5 readings was calculated and reported.

2.3.3 Testing Fabric at Different Reduction Factors

The physical and thermal comfort properties were measured in different reduction factors according to selected Taguchi orthogonal array. For keeping the fabric samples in extended state corresponding to the

determined reduction factor, a special metallic frame was prepared (Fig. 2). A 10 × 10 cm² is marked on the knitted fabric and then is mounted on the metallic frame at a predetermined extension. The extension's amount applied in fabric sample was calculated from the difference between the initial and final extended length. Physical properties of the knitted fabric such as knit density as well as air permeability, heat transfer percent and horizontal wicking were measured by mounting the fabric on the frame.

2.3.4 Measuring Physical Characteristics

Number of courses and wales per centimeter in the knitted fabrics were measured in extended states. Thickness of fabrics was measured using a thickness tester according to ASTM D1777 in relaxed state. Air permeability of extended fabrics was tested according to BS5636 standard using Shirley SDL Air permeable tester. Air pressure difference of 100 Pa was set between the two surfaces of the knitted fabric. The diameter of the clamping head was 78.5 mm². Average of five readings was calculated and then reported.

2.3.4.1 Thermal Properties

An apparatus was utilized to measure the heat transfer percent of the knitted fabrics in different extended states. This apparatus was manufactured according to guarded hot plate method. In order to provide the uniform and adjustable temperature, a hot plate was equipped with a heat measuring sensor connected to a PID control unit. Using this mechanism, the temperature with an accuracy of 1°C was adjusted. In this research, the initial temperature (T₀) of the hot plate was set at 37°C. The manufactured setup was located inside an Aluminium chamber covered with an Aluminium foil. An Infrared thermometer (Raytek MI) was placed on top of the setup for measuring the temperature during the test.



Fig. 2 — Special frame developed for applying extension

The infrared thermometer was connected to a PC computer for data acquisition. The temperature measured from the upper side of the samples were recorded five times for each sample for every 10s interval and the mean values was extracted as a temperature–time curve shown in Fig. 3. The maximum temperature value (T_{max}) and the slope of the temperature–time curve (S) at first zone was used for further analysis. The value of heat transfer was calculated using the following equation:

$$\text{Heat transfer} = \frac{T_{\text{max}} - T_0}{T_{\text{max}}} \quad \dots (2)$$

2.3.4.2 Wicking Properties

The introduced method is capable to measure the horizontal wicking area of a knitted fabric. As shown in Fig. 4, a predetermined amount of water (0.3 ml) is supplied from the bottom side of fabric at a constant rate (10 ml/h) and the tests were performed in an enclosed chamber. The water is absorbed by the knitted fabrics and it spreads continuously on the fabric surface. A camera located on top of the setup, was used to capture high resolution image from the wetted sample. This image is transferred to a

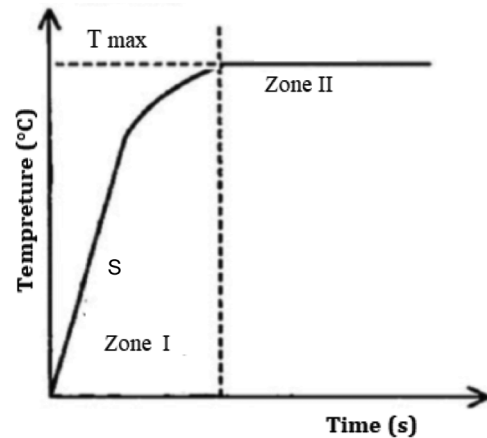


Fig. 3 — Temperature–time curve extracted from test

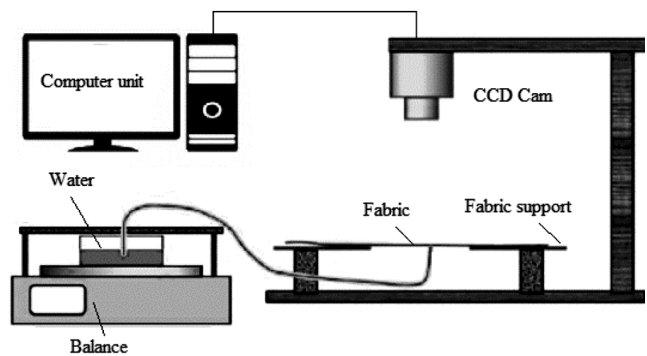


Fig. 4 — Apparatus used for measuring wicking area

Table 2 — Results of the experiments

Sample	Stitch density /cm ²	Thickness mm	Airpermeability mm/s.cm ²	Heat transfer %	Sleep of heat transfer	Wicking area mm ²	Pressure mmHg
1	0.633	221	800	0.096	26.66	16.56	38
2	0.639	208	1450	0.098	27.40	31.84	42.66
3	0.609	325	1700	0.106	30.37	68.78	48
4	0.912	238	1300	0.101	28.51	35.66	33
5	0.889	210	1750	0.114	32.22	62.42	39
6	0.903	264	1900	0.114	32.96	64.96	41
7	0.779	306	850	0.082	23.70	17.83	66.33
8	0.769	360	1200	0.093	27.13	35.66	75
9	0.788	378	500	0.089	25.92	15.28	55.33
10	0.701	468	3200	0.1	28.14	50.95	22.66
11	0.709	468	1500	0.097	27.40	33.12	21.33
12	0.756	494	2150	0.094	27.14	35.66	24
13	0.89	306	3000	0.107	30.74	62.42	17.66
14	0.888	256	3700	0.111	32.59	68.78	28.66
15	0.88	255	1900	0.092	26.29	59.87	15.66
16	0.826	408	1950	0.097	28.14	49.68	34.66
17	0.835	432	1200	0.092	25.92	44.58	17
18	0.869	396	1750	0.093	27.36	48.40	29.33

computer unit and finally the wicking area is calculated by image process technique.

3 Results and Discussion

The measured characteristics are demonstrated in Table 2.

3.1 Effect of Controllable Factors on Applied Pressure

The results demonstrated that varying the structural parameters the pressure garments with a wide range of the pressure from 17 mmHg to 66.3 mmHg have been developed. In the first step, the significant effect of controllable factors on the applied pressure is statistically analyzed using ANOVA method. The findings reveal that the parameter “Lycra count”, “fabric structure” and “reduction factor” have significant effect on the garment pressure, because the calculated “P-value” are less than 0.05. Also, the factor Lycra tension has no significant effect in the defined range.

Three readings have been recorded for each experimental condition. A signal to noise ratio analysis is used to identify the strongest effects and to determine the best factor levels for the pressure applied by compression garment. Three standard S/N equations are widely used to classify the objective function as: 'larger the better', 'smaller the better', or 'nominal the best'. However, regardless of the type of performance characteristic, a larger S/N ratio is always desirable. In this study, garment pressure has

Table 3 — S/N ratios of controllable factors on applied pressure

Level	Lycra count	Fabric structure	Lycra tension	Reduction factor
1	-27.12	-29.86	-30.21	-28.66
2	-33.45	-28.75	-30.38	-30.47
3	-	-32.26	-30.27	-31.47
Delta	6.33	3.52	0.17	3.08
Rank	1	2	4	3

been considered as the larger-the-better quality characteristics. In this case, for calculating the loss function according to 'smaller the better' and 'larger the better' are defined as follows¹⁶ respectively:

$$SN_j = -10 \log \left(\frac{1}{N} \sum_{i=1}^N \frac{1}{y_i^2} \right) \dots(3)$$

$$SN_j = -10 \log \left(\frac{1}{N} \sum_{i=1}^N y_i^2 \right) \dots(4)$$

where *n* is the number of tests; and *y_i* the experimental value of *ith* quality characteristic. By applying Eq. (4), S/N ratio for each experiment of L18 is calculated.

The S/N ratios calculated for considered controllable factors are demonstrated in Table 3. Minitab software is utilized to examine the effect of each controllable factor on the applied pressure by the prepared fabric samples. The highest S/N ratio demonstrates the strongest effects and indicates to the best factor levels for the compression garment that applied pressure to the body¹⁶. The empirical

relationships between pressure and the controllable factors are analyzed using Minitab software. Furthermore, the optimum conditions are determined. This analysis is based on combining the data associated with each level for each factor. The difference in the average results for the highest and lowest average response is the measure of the effect of that factor on garment pressure. The greatest value of this difference is related to the strongest effects of that particular factor. According to the S/N ratio analysis, factor Lycra count shows the strongest effect with a delta of 6.33 on garment pressure. Factor fabric structure is second with a delta of 3.52 and is followed by factor reduction factor with a delta of 3.08.

Figure 5 demonstrates the effect of controllable factors on the applied pressure. The findings show that higher linear density (500 denier) applies more pressure than lower linear density (140 denier). Due to the increase in linear density of the inlay yarn, the formed loops will be wider and shorter in height which leads to increase the fabric thickness and weight¹⁸. When the linear density of inlay yarn increases, tension developed in the pressure garment also increases. According to Laplace's law, the increase in tension created on the fabric is directly related to the applied pressure. Therefore, the higher the elastic modulus, the greater will be the pressure exerted by pressure garment. The fabric produced with the elastane yarn having higher linear density leads to higher elastic modulus as well as fabric thickness that in turn creates more pressure applied on the body. This result is supported by the previous study carried out by Bera *et al.*¹⁷.

The effect of fabric structure on its elastic properties is prominent. Fabric modulus reflects change of the pressure applied by the elastic knitted

fabric¹⁸. According to Laplace's law the pressure exerted on a cylindrical tube is calculated as follows:

$$P = \frac{T}{r} = \frac{2\pi E \epsilon s}{c} \quad \dots (5)$$

where P is the pressure applied on the cylinder (Pa); T , the fabric tension applied on the cylindrical surface (N/m); C , the circumference of the cylinder (m); s , the fabric thickness (m); E , the fabric modulus; R_e , the reduction factor; C_b , stands for circumferences of the fabric; and r , the radius of the cylindrical surface (m).

At the same strain value, the interface pressure increases when Young's modulus increases. This variation is related to the mechanical behavior of the fabric samples. The greater the Young's modulus, the higher is the tension needed to obtain the desired strain, which leads to higher interface pressure.

The results reveal that the fabric sample KMK creates the highest level of pressure. This is attributed to presence of the miss stitches in the fabric structure. Using the multiple miss loops leads to create a tight knit structure due to higher stitch density. Consequently, the fabric extensibility will be drastically reduced and resistance to extension as well as fabric modulus will increase. Therefore, it is expected that this structure represents higher pressure. The results show that this structure can provide a wide pressure level of 45 mmHg to 64 mmHg and accordingly. It can be categorized in the pressure garments creating high pressure.

From Fig. 5, it can be concluded that the least range of the applied pressure (17mmHg–25 mmHg) is provided by fabric sample KT2M. It could be due to effect of several tuck stitches associated in the fabric structure. A tuck stitch is consisted of a held loop and one or more tuck loops. Loop accumulation at tucking places causes an increase in the fabric thickness in comparison to the knitted fabrics containing less tuck stitches. This causes an increase in the pressure applied by the knitted fabric for a given radius of the cylindrical surface.

When the fabric circumference is identical and the other parameters are kept invariable, the thickest knitted fabric creates more internal force to the cylinder¹⁸. In addition, course-wise extensibility of the knitted fabric having tuck loops is increased because tuck loops pull the held loops downwards, pushing them to spread width-wise and provide required yarn available for extensibility¹⁴. This phenomenon decreases the fabric modulus as well as pressure applied in a determined tube diameter.

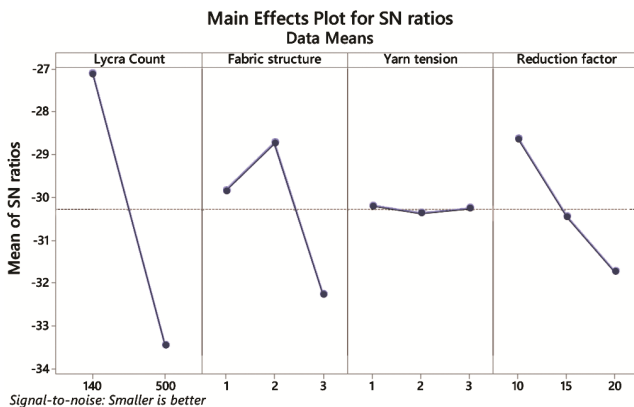


Fig. 5 — Effect of controllable factors on applied pressure

Therefore, an increase in number of tuck loops leads to two opposite out comings; the former increases and the latter decreases the applied pressure. The effect of course-wise extensibility seems to be dominant.

The more the tuck loops contribute in fabric structure, the lower is the modulus of the weft knitted fabrics. Therefore, fabric sample KMT which possess less tuck loops, creates more pressure applied on the body. The pressure range provided by this knitted fabric is 25 mmHg to 35 mmHg. Greater reduction factor means more fabric stretchability and as a result more applied pressure. According to following equation, more stretchability (S_f) is created when the greater reduction factor (R_e) is used ¹⁷:

$$S_f = \frac{100 \times R_e}{100 - R_e} \quad \dots (6)$$

where reduction factor is defined as the ratio of the fabric circumference at relaxed state to the cylinder circumference. In spite, it should be stated that measuring the pressure applied by compression garment in a real human body is more complex and subject to greater variability as compared to measuring it on a rigid tube. It requires considering the dynamic nature of the body, accounting for individual differences, and understanding the subjective perception of the pressure. The non-uniform cylindrical shape of the human body as well as varying thicknesses of soft tissues can affect the pressure distribution and transmission from the compression garments to the underlying tissues and structures. Also, the measuring of the applied pressure is mostly carried out in a static state. Body movement can alter the pressure distribution and consistency, making it challenging to obtain accurate and consistent measurements. Therefore, the compression garment developed in this research will create a different pressure range on the human body.

3.2 Effect of Controllable Factors on Fabric Air Permeability

In the first step, the significant effect of controllable factors on the applied pressure has been statistically analyzed using ANOVA method. The P-values of the parameters "Lycra count", "fabric structure", "yarn tension" and "reduction factor" are 0.038, 0.006, 0.27 and 0.012 respectively. The findings reveal that the parameter "Lycra count", "fabric structure" and "reduction factor" have significant effect on the air permeability, because the calculated "P-value" are less than 0.05. Also, the factor Lycra tension has no significant effect in the defined range. In this study, garment pressure has

been considered as the larger-the-better quality characteristics. The S/N ratios calculated for controllable factors are demonstrated in Table 4.

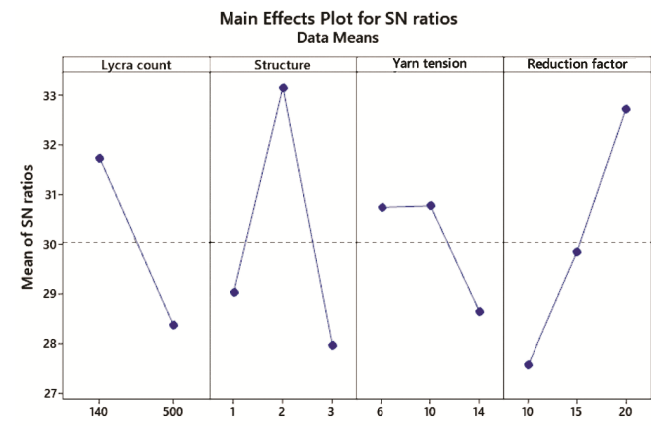
According to the S/N ratio analysis, factor fabric structure shows the strongest effect with a delta of 5.17 on air permeability. Factor reduction factor is second with a delta of 5.14 and is followed by factor Lycra count with a delta of 3.36.

From Fig. 6, it can be concluded that fabric sample KT2M demonstrates the highest air permeability. In order to analyze the effect of fabric structure on air permeability, it is necessary to consider the simultaneous effect of the fabric thickness and extensibility in a specific reduction factor. As already explained, the tuck loops increase the fabric thickness. This increases the resistance of the knitted fabrics against air current due to creating more air pockets through the fabric structure. Besides, the tuck loops increase the fabric extensibility which leads to create an open structure as well as more air permeable fabric. The results showed that the effect of fabric extensibility is the dominant. Also, the findings revealed that a greater number of tuck loop leads to more fabric extensibility as well as opener structure.

In comparison to the knitted structure containing tuck stitches, the fabrics which is composed of the knit and miss stitches (KM2) demonstrates more stitch density and lower extensibility. This means that this fabric is less permeable. Also, there is a direct

Table 4 — S/N ratios of controllable factors on air permeability

Level	Lycra count	Structure	Yarn tension	Reduction factor
1	31.72	29.03	30.73	27.57
2	28.36	33.13	30.76	29.84
3	-	27.96	28.64	32.71
Delta	3.36	5.17	2.12	5.14
Rank	3	1	4	2



Signal-to-noise: Larger is better

Fig. 6 —Effect of controllable factors on air permeability

relationship between air permeability and reduction factor. Fabric density decreases significantly when the reduction factor increases. This creates an open and more permeable structure. The results showed that the elastane yarn’ count has a significant effect on the air permeability. The fabric containing thicker elastane yarn represents more resistant to extending. This result is also confirmed by previous study²⁰. Therefore, using the thicker elastane yarn creates a more closed as well as lower permeable knitted structure.

3.3 Effect of Controllable Factors on Wicking Properties

In the first step, the significant effect of controllable factors on the wicking area is statistically analyzed using ANOVA method. The findings reveal that the parameter “Lycra count”, “fabric structure” and “reduction factor” have significant effect on the garment pressure, because the calculated “P-value” is less than 0.05. Also, the factor Lycra tension has no significant effect in the defined range.

The calculated SN-ratios are given in Table 5. According to the S/N ratio analysis, reduction factor shows the strongest effect with a delta of 5.67 on wicking area. Factor fabric structure is second with a delta of 5.47 and is followed by factor Lycra count with a delta of 5.14.

Figure 7 depicts the effect of controllable factors on the wicking area. The two characteristics which are

Table 5 — S/N ratios of controllable factors on wicking area

Level	Lycra count	Fabric structure	Lycra tension	Reduction factor
1	66.56	64.36	63.54	60.83
2	61.42	66.53	64.36	64.62
3		61.07	64.06	66.51
Delta	5.14	5.47	0.82	5.67
Rank	3	2	4	1

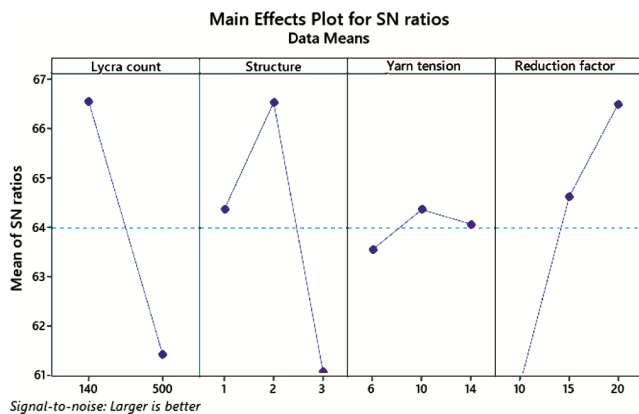


Fig. 7 — Effect of controllable factors on wicking area

used to predict fabric wicking performance are capillary pressure through the fabric structure and permeability. Therefore, the controllable factors which affect the fabric air permeability can influence the wicking area of the knitted fabrics. This means more permeable the fabric structure; the more moisture is able to pass through the fabric’s capillaries²¹. This is because the speed of moisture movement through the vacant spaces is faster than the moisture movement through the fibres. The higher the fabric reduction factor, the more open is the fabric pores and the less fabric thickness. Therefore, in order to increase the wicking performance, higher reduction factor should be used. Gupta *et al.*¹² reported that the more stretchable is a cloth, the more it will be able to pass moisture through its structure. The fabric with lower stitch density creates more capillaries to transfer the moisture. The results revealed that fabric sample KT2M represents the highest wicking area within the produced knitted fabrics. This fabric is more permeable in extended state compared with other samples which logically represents higher wicking performance. Accordingly, the knitted sample KM2 demonstrates lower wicking performance due to denser structure. Such a fabric structure creates less capillaries to transfer the moisture as well as less wicking area. According to results reported by Čiukas *et al.*²¹, the higher percentage of the elastic yarn in the fabric structure is due to the lower moisture transfer through the fabric. This means that in the stretched state, there is more space between the loops, which allows moisture to pass through the liquid phase.

3.4 Effect of Controllable Factors on Thermal Properties

The significant effect of controllable factors on the thermal properties is statistically analyzed using ANOVA method (Table 6). The findings reveal that the parameter fabric structure and reduction factor have significant effect on the heat transfer per cent and temperature-time curve’s slope. Also, the factor Lycra tension and Lycra count have no significant effect in the defined range. The results also show that for both considered thermal properties, factor fabric structure has the strongest effect and factor reduction has the second effect.

Figure 8 demonstrates the effect of controllable factors on the thermal properties in terms of heat transfer per cent and temperature-time curve’s slope. Both thermal properties considered in this study reflect the thermal conductivity of the knitted fabric. Oğlacioğlu

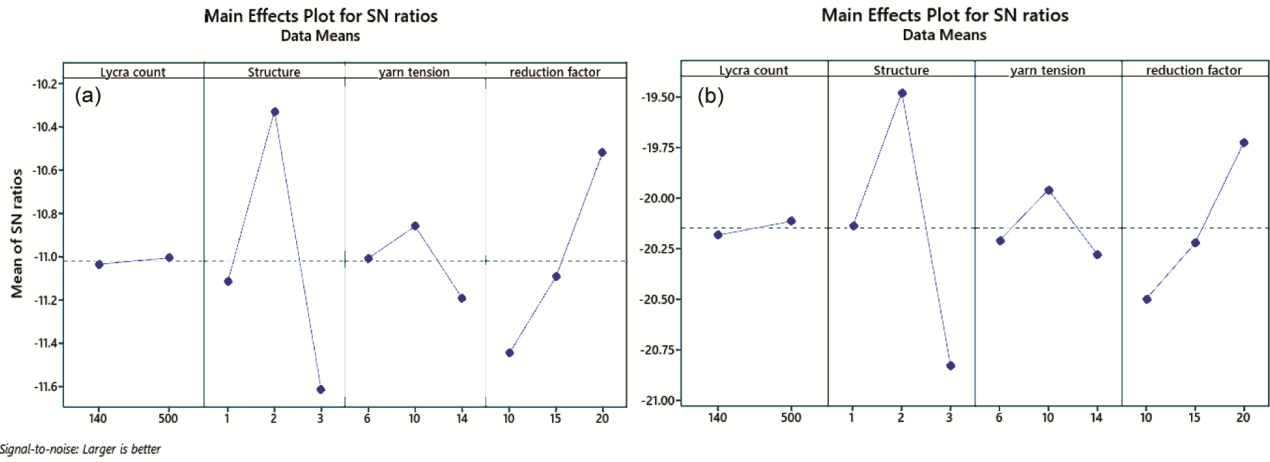


Fig. 8 — Effect of controllable factors on thermal properties (a) heat transfer % and (b) temperature-time curve slope

Table 6 — Results of the ANOVA analysis

Source	DF	Seq SS		Adj SS		Adj MS		F		P	
		H _T %	Slope	H _T %	Slope	H _T %	Slope	H _T %	Slope	H _T %	Slope
Lycra count	1	0.0038	0.0216	0.0038	0.0216	0.0038	0.0216	0.02	0.09	0.898	0.767
structure	2	5.067	5.4929	5.0670	5.4928	2.5335	2.7464	11.60	11.73	0.002	0.002
Lycra tension	2	0.336	0.3405	0.3362	0.3404	0.1681	0.1702	0.77	0.73	0.489	0.507
Reduction Factor	2	2.630	1.8515	2.6303	1.8514	1.3151	0.9257	6.02	3.95	0.019	0.044
Residual Error	10	2.184	2.3410	2.1840	2.3409	0.2184	0.2341	-	-	-	-
Total	17	10.22	10.0473	-	-	-	-	-	-	-	-

and Marmarali²² reported that the heat transfer percent is inversely related to the fabric thickness. Also, heat transfer per cent decreases when the amount of entrapped air is increased. A fabric having thick and open structure can have high thermal conductivity than a thin and tight structure fabric. As the fabric samples having tuck stitches are extended, they become thin and open in structure, due to less fabric modulus. This can reduce the amount of entrapped air and hence increase the heat transfer percent as well as temperature-time curve's slope. In contrast, the knitted fabric contains miss and knit stitches create a thin and thigh structures. Heat conductivity depends upon the available surface area in contact for conduction. In the present study, as the fabric gets extended, it becomes thin and open in structure²³. Therefore, the fabric area in contact with the test plates decreases, leading to a reduction in the amount of heat conducted. Accordingly, an increase in reduction factor causes increasing the amount of heat conducted.

3.5 Relation between Applied Pressure and Comfort Properties

In order to examine the relation between the applied pressure and the comfort properties, Pearson correlation values were determined. Table 7 shows the correlation coefficients and corresponding p-values. The results shows that all considered comfort properties have significant correlation with each

Table 7 — Correlation values between comforts and applied pressure

Parameter	Air permeability	Heat transfer	Heat slope	Wicking area
Heat transfer	0.568 0.0148*			
Heat slope	0.607 0.008*	0.982 0.000*		
Wicking area	0.720 0.001*	0.746 0.000*	0.783 0.000*	
Pressure	-0.526 0.025*	-0.238 0.341	-0.186 0.459	-0.402 0.098

*Significant at 95%.

other. But there is no significant correlation between the applied pressure and heat transfer, heat slope and wicking area. The exception is air permeability. It might be attributed to this fact that the parameter affecting the pressure could not influence the comfort properties.

4 Conclusion

This study focuses on the effect of structural and process variables, such as elastane yarn count, and elastane yarn tension during yarn positive feeding,

reduction factor and fabric structure on the thermal comfort properties of the compression in terms of air permeability, heat transfer per cent and wicking rate. Pressure garments with a wide range of the applied pressure from 17 mmHg to 66.3 mmHg were developed. The results reveal that the garment samples containing knit and miss stitches apply the highest amount of pressure while the samples having knit and tuck stitches create the lowest pressure. Also, increasing the linear density of the elastic yarn and using a higher reduction factor provide a higher pressure. The results show that the fabrics which apply more pressure on the body possess more tight structure when they are extended. Therefore, they show less air permeability, heat and moisture transfer. Also, for a certain fabric structure, an increase in reduction factor leads to open structure and creating more pressure. Consequently, air permeability and the heat and moisture transfer are increased. Samples which apply less pressure, are more permeable and transfer greater amount of heat, and moisture through their structure due to creation of an open structure in extended state.

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