ANALYSIS OF THERMAL PROPERTIES AFFECTED BY DIFFERENT EXTENSION LEVELS OF COMPRESSION SOCKS

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Abstract: *The aim of this research is to analyze the effect of various extension levels on thermal properties including thermal conductivity and thermal effusivity of compression socks. Compression socks are recommended as tool for compression therapy but discouraged because poor performance regarding its interaction to thermal properties especially the thermal conductivity and effusivity. The problem of this research is to investigate how much the circumferential extensibility of compression socks affects its thermal comfort properties. Here, gradual increase in extension values of strips depicts the different circumferences of the legs. For extension, we introduced novel extension frame attached with movable gears and revolving handle. The aim of this research is to analyze effect of gradient elastic elongation [%] on thermal effusivity [W.s$^{1/2}$/m^2.K] and thermal conductivity [W/m.K] in relaxed (0% extension) and extended state (up to 70% extension). To extend the compression socks a novel extension frame was used. Conclusively, we found that as elastic elongation increases, thermal conductivity and thermal effusivity changes significantly. We also have concluded for extension above 70% that the trends changes and comfort properties started to decline. Out of three socks samples, the best one was rib structured compression socks sample.*

Key words: *Compression socks, thermal effusivity, thermal conductivity, novel extension frame.*

1 INTRODUCTION

Compression socks are a highly acclaimed textile garment for pressure exertion on the lower part of the leg. It is used to reduce venous hyper pressure [1]. Physical and constructional properties of compression socks are the most important because their properties directly relate to the type of patient and intensity of the disease. The extent of compression, that a patient can easily manage, depends on stage (limb size and shape) of venous disease and his activities (mobility, age) [2]. Socks, worn inside the shoes, are used to stabilize wearer's comfort, level of interaction and ease against its rasping with footwear. They must exhibit excellent mechanical (extensibility and elasticity recovery) along with optimized comfort properties (sensorial and thermo-physiologic features). Excellent stretch and recovery properties do not restrict the wearer's movement during activities and provide positive feeling over skin by transferring optimum heat, moisture and air through fabric [3, 4].

Socks selection keeps foot dry and cool, no accumulation of moisture but prompt flow of generated sweat, abstain maceration of skin and inhibit bacterial growth that can cause blisters and athletic deceases. To develop such type of dry-socks, it must possess good wicking action necessary to keep the foot dry and warm. The transport of both moisture vapor and liquid away from the body is called moisture management [5, 6] and is mechanized by two processes named as vapor's conduction (diffusion) and by convection processes.

Seshadri et al. studied the use, compliance and efficacy of compression socks. In this research, they analyzed 3144 patients for tertiary venous practice and concluded that only 21% patients uses stockings on daily basis, 12% most days, 4% used less option, 63% don't use; inquired the reasons were: 30% unable to give reason, 25 not recommended by physician, 14% did not help, 14% binding off, 8% too hot to wear and 2 % limb soreness, 2% due to itching, 2% others (cost and work station). As far as pressure exertion and graduation (%) in socks plays an important role to control re-occurrence of venous ulcer and venous insufficiency, it should exhibit optimum comfort properties to regulate heat and moisture transfer (comfortness) generated during different physical activities of patients [7].

Gupta et al. (2011) studied the comfort properties of pressure garments at different extension levels from 0 to 60%. They extended the fabric by designing a frame (30×30 cm^2) made up of acrylic sheet and took sample of 14.4×20 cm and marked square of 10×10 cm^2. But for compression socks this frame cannot be recommended as socks circumference at ankle is very low and higher at calf. For Compression class III and IV it is very hard to extend to 60% precisely [8]. Wang et al. (2013) mentioned the same while investigating dynamic pressure attenuation of elastic fabric for compression garment [9].

Fundamental parameters which govern the thermo-physiological properties of fabrics are fibre type, fibre conductivity, fibre moisture regain, yarn count, yarn twist per inch, yarn structure, spinning process, fabric structure, fabric loop length, fabric thickness, fabric porosity and finishing treatments [10].

As compression socks are directly in contact with skin, normally known as second skin. Heat flow through the socks takes place through conduction which relate to the parameters especially thermal conductivity, air permeation, thermal effusivity influenced by area through which heat is conducted and difference of temperature between skin and environment and thickness of fabric, fabric porosity (fibers and yarns packing density).

Thermal effusivity is also known as thermal absorptivity. Warm and cool feeling at the time of contact to textile fabrics can be described by thermal effusivity values. It means initial feelings when a human body touch to a textile fabric was introduced by Hes [11]. He rated that higher the thermal absorptivity of the fabric, the cooler it will be in its feeling. Thus derived thermal absorptivity b [$W.s^{1/2}/m^2.K$] relation as given below:

$$b = (\lambda.\rho)^{1/2} \quad (1)$$

As far as thermal absorptivity is concern, thermal conductivity is also considered as main parameter used to evaluate thermo-physiological properties of compression socks. It is transfer of heat from one part of a body to another. It can be defined as ability of material to transmit heat and it is measured in watts per square meter of the surface area for a temperature gradient of 1 K per unit thickness of 1 m. It is denoted by λ [12].

Marmarali proved that thermal absorptivity depends on the surface profile of the fabric. Smooth surface provides maximum contact points, and heat freely transfers between the skin and the fabric. More heat transfers mean higher thermal absorptivity and intensified warm-cool feeling [13].

The aim of this study was to investigate the effect of gradual increase in elastic elongation of compression socks using novel extended frame on thermal effusivity and thermal conductivity. These are necessary parameters required to get rid of sweat accumulation between garment and skin in relaxed and extended state.

2 MATERIALS AND METHOD

Three type of compression socks were purchased and structurally analyzed with great precision and accuracy.

2.1 Visualization of knitted loops

All the three socks samples were evaluated structurally using digital highly magnified microscope at magnification of level of 30X. Compression socks being more compact were stretched to 100% extension prior to peer inside the loops to investigate its structure and path of the knitted loops. So we adopted the same procedure and stretched the socks to 100%. Stretched loop's unit cell of scanned knitted images was drawn using 3D-Texmind software as shown in Figure 1.

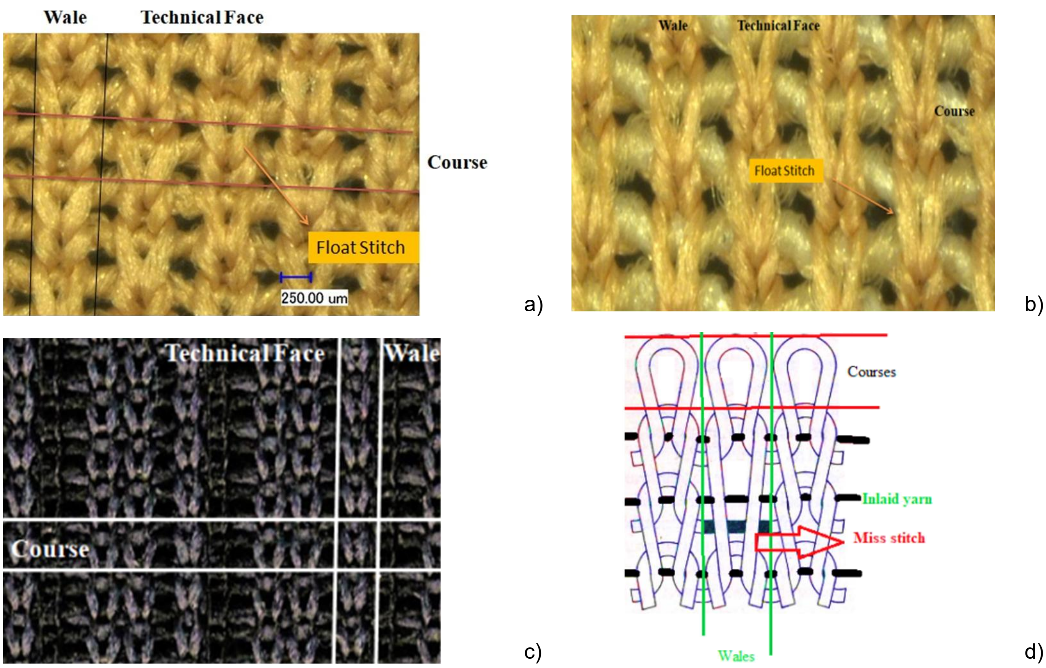


Figure 1 Knitted scanned images (a, b, c) and drawn loops (d) [14]

2.2 Physical testing of compression socks

Table 1 Physical testing of compression socks in relaxed state (0% extension)

Sample codes	Position	BIISJ*	BIIISJ*	DGIIRIB*
Socks Circumference [cm]	ankle/calf	16.6/23	16/25.6	16.4/26
Courses/inch	ankle/calf	57/58	49/49	56/58
Wales/inch	ankle/calf	52/42	49/36	42/27
Stitch/inch^2	ankle/calf	460/277.6	372/273	364/343
Thickness b [mm]	ankle/calf	0.75	0.95	1.20
Areal Density (GSM)	ankle/calf	308.80/291.80	378.47/368.47	350.97/292.47

*B= Beige, II, III= compression class, SJ= single jersey, RIB= rib structured

2.3 Marking and cutting of socks

All the three socks samples, BIISJ, BIIISJ and DGIIRIB, were marked with a square line on their surface to dimensions (8×8 cm^2) of each. All the three socks strips were washed afterwards and then installed on novel extension frame to extend it equal to circumference of plastic leg (circumference: 23 cm) simultaneously

2.4 Washing procedure

Prior to extend the socks using novel extension frame, tensile and pressure characterization, we washed the socks as per European guideline i.e. hydro-extraction for 2 minutes. After that socks samples were dried (flat drying), relaxed and conditioned for 24 hours under standard atmospheric condition (RH 65±5%, temperature 20±2°C) (Wegen-Franken, Roest, Tank, & Neumann, 2006).

2.5 Novel extension frame

This frame is designed to extend the socks to maximum 70% relates to intensity of the disease. This frame is drived using combination of three gears as shown in Figure 2. Middle gear, connected with revolving handle, drives the two movable jaws in opposite direction.

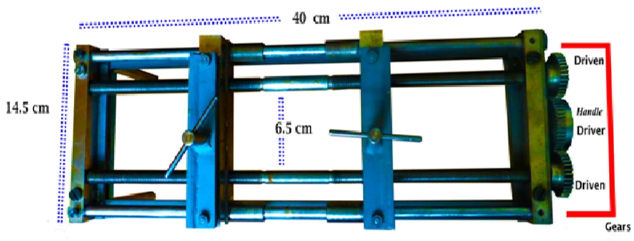


Figure 2 Novel extension frame

Maximum distance between jaws can be achieved up to 36 cm. As we rotate the handle, the jaws move apart and extend the fabric to required level (up to 70% and more). Total length of frame is 40 cm; width of jaws is 14.5 cm.

2.6 Thermal properties tester (TCi)

C-Therm (TCI tester) was used to analyze thermal properties of compression socks. This system consists of an external sensor, software for computer and control electronics. The standard test method EN 61326-2-4:2006 was used for this testing using TCI [16]. This test was performed under room temperature. The results are reported in Table 2.

Table 2 Thermal effusivity, conductivity and stitch density results in relaxed and extended state

Socks code	Position	Parameters	Elongation [%]							
			0 (Relaxed)	1	20	30	40	50	60	70
BIISJ	ankle	Thermal effusivity [W.s$^{1/2}$/m^2.K]	264.43	263.15	261.87	260.70	259.530	256.61	253.70	248.50
	calf		242.22	240.16	238.09	237.30	236.520	230.28	224.05	219.37
	ankle	Thermal conductivity [W/m.K]	0.1166	0.116	0.1157	0.1153	0.11495	0.1139	0.1129	0.1122
	calf		0.1090	0.1085	0.108	0.1076	0.1071	0.1050	0.1029	0.1013
	ankle	Stitches/inch^2	460	431	411	390.70	368.74	350	339	323.50
	calf		377.6	357	335	312	298	279	266	250
BIIISJ	ankle	Thermal effusivity [W.s$^{1/2}$/m^2.K]	219.20	218.05	216.91	212.77	208.63	203.65	198.68	195.50
	calf		216.24	215.62	215.01	212.20	209.39	203.90	198.41	193.05
	ankle	Thermal conductivity [W/m.K]	0.1012	0.101	0.1004	0.0991	0.0977	0.09600	0.0943	0.0929
	calf		0.0999	0.100	0.0999	0.0989	0.0980	0.0962	0.0943	0.0850
	ankle	Stitches/inch^2	372	351.51	330	309	288	270	252	232
	calf		273	252	230	208.2	194	179	164.4	150
DGIIRIB	ankle	Thermal effusivity [W.s$^{1/2}$/m^2.K]	170.71	178.68	186.66	190.35	194.04	198.70	200.90	210.20
	calf		190.38	193.41	196.44	199.35	202.27	201.77	201.27	200.60
	ankle	Thermal conductivity [W/m.K]	0.0850	0.088	0.0903	0.0915	0.0928	0.0934	0.0940	0.0950
	calf		0.0916	0.093	0.0936	0.0946	0.0955	0.0949	0.0952	0.0975
	ankle	Stitches/inch^2	364	340	315	299	283	258	232	207
	calf		243	226	209	201	183	166	157.6	149

Table 3 Statistical analysis of thermal properties

Parameters	Socks Code	Position	Socks Code	R-Square Value	p-Value <0.05	Correlation	Regression Model
Thermal effusivity [W.s$^{1/2}$/m^2.K]	BIISJ	ankle	BIISJ	91.61	*0.001	-0.96	Y=265.9 - 0.2093X
		calf		89.83	*0.001	-0.95	Y= 244.5 - 0.3151X
	BIIISJ	ankle	BIIISJ	96.57	*0.001	-0.98	Y= 221.9 - 0.3651X
		calf		91.44	*0.001	-0.96	Y= 219.8 - 0.3387X
	DGIIRIB	ankle	DGIIRIB	97.29	*0.001	0.99	Y= 173.5 + 0.6507X
		calf		75.33	*0.005	0.87	Y=192.8 + 0.1545X
Thermal conductivity [W/m.K]	BIISJ	ankle	BIISJ	95.66	*0.001	-0.98	Y= 0.1169 - 0.00001X
		calf		89.64	*0.001	-0.95	Y= 0.1100 - 0.00010X
	BIIISJ	ankle	BIIISJ	96.34	*0.001	-0.98	Y= 0.102 - 0.000127X
		calf		69.12	*0.011	-0.83	Y= 0.126 - 0.000172X
	DGIIRIB	ankle	DGIIRIB	91.93	*0.001	0.96	Y= 0.086+ 0.000132X
		calf		87.70	*0.001	0.94	Y= 0.092+ 0.000068X

3 RESULTS AND DISCUSSION

3.1 Effect of elastic elongation on thermal effusivity at ankle and calf portions

Table 2 and Figure 3 (a, b) depicts that as elastic elongation increases from 0% extension to 70% extension while thermal effusivity of BIISJ and BIIISJ samples decreases from 264.438 and 219.207 to 248.50 and 195.50 [W.s$^{1/2}$/m^2.K]

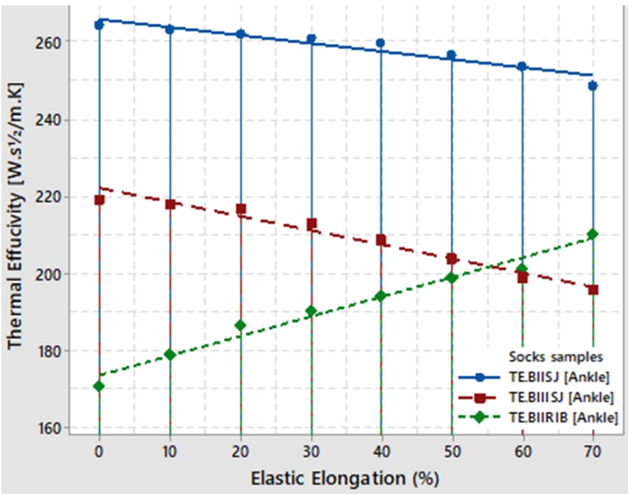
For DGIIRIB, it increases from 170.71 to 210.20 [W.sec$^{1/2}$/m^2.K]. The same trend was observed for thermal effusivity at calf portion which also decreases for BIISJ and BIIISJ from 242.22 and 216.40 to 219.37 and 193.056 [W.s$^{1/2}$/m^2.K]. For socks sample DGIIRIB, it increases from 190.38 to 200.20 [W.s$^{1/2}$/m^2.K].

Regression analysis of effect of elastic elongation on thermal effusivity was evaluated using Minitab 17 and are given in Table 3.

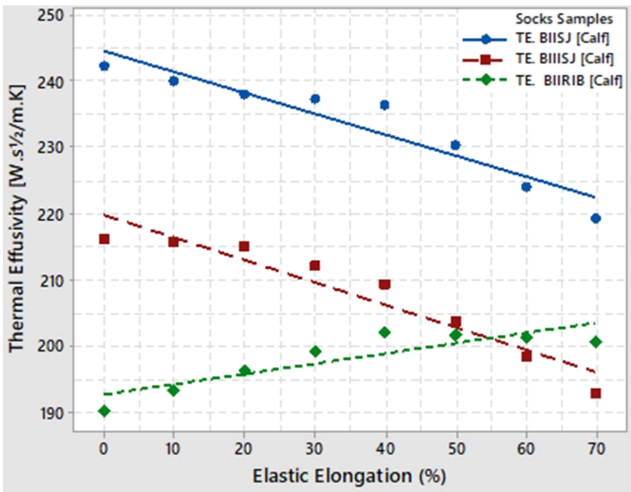
3.2 Effect of elastic elongation on thermal conductivity at ankle and calf portions

In Figure 4 we found that as the elastic elongation increases at ankle from relaxed state to extended state, thermal conductivity of samples BIISJ and BIIISJ decreases from 0.11660 and 0.10127 to 0.11223 and 0.09292 [W/m.K]. While thermal conductivity of socks samples DGIIRIB increases from 0.085 to 0.09504 [W/m.K] as elastic elongation increases. Thermal conductivity at calf portion which also decreases of samples BIISJ and BIIISJ from 0.1090 and 0.0999 to 0.1013 and 0.0850 [W/m.K].

While thermal effusivity increases of samples DGIIRIB, as elastic elongation increases, it increases from 0.085 to 0.0904 [W/m.K]. The reason of decrease in thermal conductivity of samples BIISJ and BIIISJ is due to decrease in stitch density and increase of pore size. Higher pore sizes because more air entrapped inside the fibers of yarns.

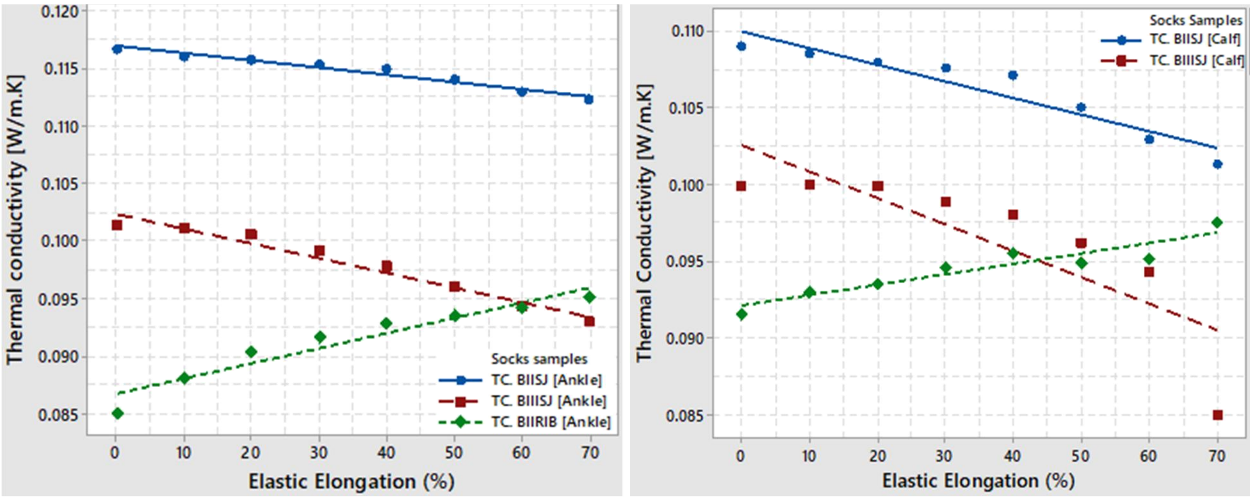


a)



b)

Figure 3 Thermal effusivity affected by different extension levels (a) ankle and (b) calf



a) b)

Figure 4 Thermal conductivity affected by different extension levels (a) ankle and (b) calf

4 CONCLUSION

In this research the comfort properties, thermal effusivity and thermal conductivity, of all three socks samples were evaluated and finalized and the socks sample DGIIRIB exhibited excellent results of thermal effusivity and thermal conductivity as elongated to 70%. Out of all three socks samples we found the best one regarding the easiness and optimized comfort level and DGIIRIB socks sample can be recommended as best to encounter hot microclimatic environment.

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