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Statistical Modeling of Thermal Properties of Biobased Compostable Gloves Developed from Sustainable Polymer

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Abstract: Polylactic acid (PLA) is a biodegradable and compostable polymer obtained from annually renewable resources and is acknowledged to be sustainable and non-polluting polymer with substantial commercial prospective as a textile fiber however, there is lack of literature on apparel applications of this polymer. Therefore in this study it was aimed to develop biobased compostable gloves from PLA draw textured melt spun yarns and to examine the effect of yarn linear density, fabric structure and stitch density on thermo-physiological comfort and moisture management properties of PLA based gloves. 100 % PLA based multifilament yarns of two different linear densities were melt spun and later draw textured on false twist texturing machine to be used for gloves knitting. Single jersey and rib structures were produced with two different stitch densities to investigate their effect on thermal conductivity, thermal resistance, relative water vapour permeability, air permeability and moisture management properties of the gloves. Minitab statistical software was employed to analyze the results of test samples. The coefficients of determinations (R^2 values) presented good estimation capability of the established regression models. The outcomes of this research may be useful in determining suitable manufacturing requirements of PLA based gloves to accomplish precise thermo-physiological and moisture management properties.

Keywords: Polylactic acid, Melt spinning, Texturing, Sustainability, Gloves

Introduction

The physical properties and structure of Polylactic acid (PLA) has been the subject of multiple studies, indicating that this polymer is equipped with substantial commercial prospective as a textile fiber. PLA is considered to be an eco-friendly polymer as compared to conventional PET [1]. The monomer of PLA is sustainable and the raw material of PLA (such as corn) is both renewable and non-polluting, eliminates the use of a finite supply of oil as a raw material [2]. Since the quantity of corn used up in the manufacturing of PLA fibers is not greater than 0.02 % of the entire corn production in the world therefore, PLA manufacturing from corn will not consequence in a food disaster [3]. PLA needs 25-55 % less fossil resources in its production as compared to the production of oil-based polymers [4]. Moisture management and wicking properties of PLA fibers are considered better to that of PET therefore, PLA could be an interesting choice to be used in apparel applications [5,6]. PLA fibers have the ability to wick moisture faster without holding huge quantity of water due to its lower contact angle compared to PET which aids in sports applications [1,7]. Despite of all these advantages of PLA over petroleum based polymer, PLA polymer has not been used much in apparel applications.

Protection of hands is very important, because hands are exposed to several hazards (chemical skin absorption, severe cuts or scratches, abrasions, punctures, chemical burns, extreme temperature, vibration, impacts, biologic contamination, electrical charges, etc.) depending on the workplace risks. Gloves, the physical barrier between hazard and skin, are the most effective protection solution for reducing accidents at the workplace. The appropriate type of glove should be selected according to the type of activity, objects and environmental conditions. Besides protection, proper fit, flexibility, softer feeling and also comfort is taken into consideration for the performance and long term use of the gloves. Knitted gloves are commonly used for light assembly activities. They have some advantages such as better fit on the wearer's hand given by increased formability of knitted fabrics, one stage production process, and the possibility of using different yarn combinations. The next to skin material in the gloves is usually composed of synthetic fibres and is responsible for transferring the sweat to the outer layer by wicking. As PLA displays better wicking properties than other synthetic fibers, therefore could be an interesting material to be used in gloves.

Awais *et al*. [8] developed cut resistance gloves with virgin and recycled PPTA fiber and found that gloves produced from recycled fibres accomplished considerably superior cut resistance owing to the displacement of fibrils causing in dissipation of energy. Ertekin and Kirtay [9] investigated the cut resistance of gloves produced from para aramid fabrics. Cimilli *et al*. [10] examined comfort characteristics of knitted fabrics produced from various kinds of fibers and concluded that fabric's comfort characteristics are mainly dependent on type of fiber along with properties of fabrics such as thickness, areal density and packing density. Oglakcioglu and Marmarali [11] examined thermo-physiological characteristics of different knitted structures and observed that rib and interlock knit structures presented greater thermal

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resistance than single jersey structures whereas single-jersey knit structures showed higher water vapor permeability. Several researchers studied the effect different fiber types and their structure on thermo-physiological properties of different fabrics and found that distinctive fibers enhanced the thermo-physiological properties of fabrics [12].

Majority of the studies described in the literature has concentrated on the examination of thermal properties of fabrics knitted from petroleum based polymers, such as polyester's, elastane's and polyamide's however there isn't any literature available on the examination of thermo-physiological comfort properties of gloves knitted from biobased polymers such as polylactides. The thermo-physiological and moisture management characteristics of knitted gloves containing PLA are yet to be investigated thoroughly therefore, the objective of the current research is to investigate the effect of yarn linear density, fabric structure and stitch density on thermal conductivity, thermal resistance, relative water vapour permeability, air permeability and moisture management properties of gloves produced from PLA draw textured melt spun yarns. Minitab statistical software [17] was employed to analyze the results of test samples. The coefficients of determinations (R^2 values) presented good estimation capability of the established regression models. The outcomes of this research may be useful in determining suitable manufacturing requirements of PLA based gloves to accomplish precise thermo-physiological and moisture management properties.

Experimental

Polylactic acid with ≥99 % L-isomer stereochemical purity was purchased from Total|Corbion (Netherlands). DSC analysis revealed that the melting point of the polymer was 175 °C and the crystallinity content was about 75 %. Before extrusion the polymer was dried at 100 °C in a vacuum oven for 6 hours and after drying the moisture content in the polymer was 120 ppm. Melt spinning experiments were performed on Fournè high temperature single component melt spinning machine. The machine consists of single screw extruder to feed the material. Polymer is fed into extruder through a hopper and then melted at 230 °C in the extruder. The melt from the single screw extruder is transported to spinning head in a metered quantity with the help of spinning pumps. Spinnerets are constructed in such a way that uniform output of the material is maintained. Quenching zone was present below the spinneret area, where filaments were cooled at 18 °C by maintaining the cool air velocity of 0.5 m/s. The winding zone consists of take up roller, four stretching rollers (godets) and the winder. The take up roller as well as the stretching rollers (godets) were heated at 80 °C. Multifilament partially oriented yarns (POY) of PLA were produced on melt spinning machine of two different linear densities (dtex) and their properties are shown in Table 1.

Table 1. Yarn properties before and after texturing

Properties	Unit	Yarn type 1	Yarn type 2
Linear density before texturing	dtex	300	270
Tenacity before texturing	cN/tex	20.22	18.04
Elongation before texturing	%	63.29	78.88
Draw ratio at texturing	N/A	1.8	1.8
Linear density after texturing	dtex	167	150
Tenacity after texturing	cN/tex	17.14	15.39
Elongation after texturing	%	57.60	67.08

Yarn linear density (dtex) was measured by DIN EN ISO 1973 standard testing method whereas yarn tenacity (cN/tex) and elongation (%) were tested by standard testing method DIN EN ISO 2062. A view of different sections of melt spinning machine is shown in Figure 1.

After spinning, PLA-POY multifilament yarns were draw

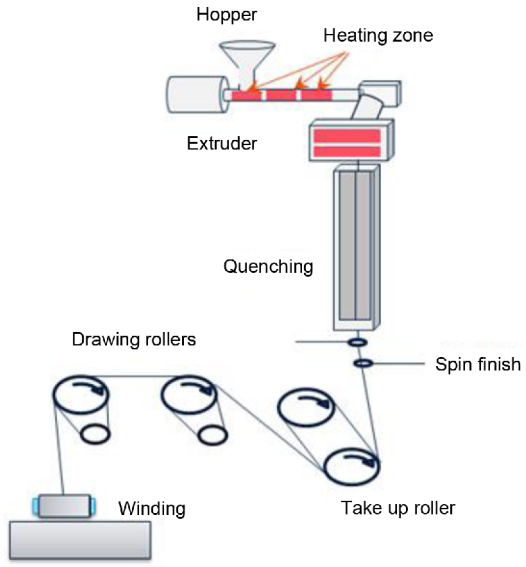

Figure 1. Schematic diagram of melt spinning machine.

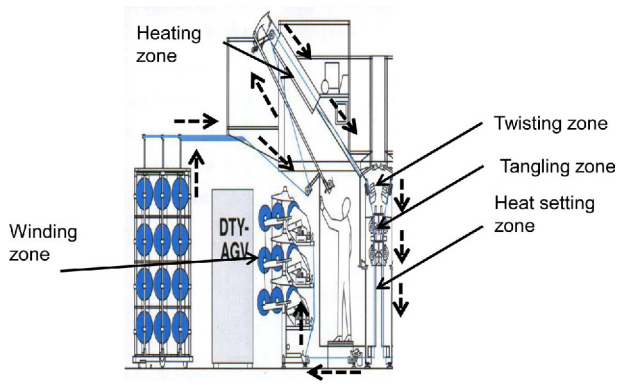

Figure 2. False twist texturing machine.

Table 2. Process parameters for false twist texturing machine

No.	Linear density before texturing (dtex)	First heating temperature (°C)		No. of ceramic discs in twisting zone	Draw ratio	Second heating temperature (°C)	Speed (m/min)	Linear density after texturing (dtex)
		Long heater	Short heater					
1	300	190	75	9	1.8	50	400	167
2	270	190	75	9	1.8	50	400	150

textured on Barmag AFK2 false twist texturing machine as shown in Figure 2.

Texturing of multifilament yarns is done in order to obtain similar properties to that staple fiber yarn for apparel applications. False twist texturing machine consisted of a yarn holding stand, where the yarn bobbins were placed. The yarns were initially drawn with a vacuum pistol and passed through the first heating zone. First heating zone consisted of long heater and a short heater. The temperatures of long and short heaters were 190 °C and 75 °C respectively. The heated yarn was passed through the cooling section in order to relax the yarn for further mechanical stresses and then passed through the twisting zone which consisted of a number of ceramic discs. The twisted yarn was then passed through the tangling zone and then through the second heating zone. The temperature of second heating zone was kept at 50 °C. The draw textured yarn (DTY) was then wound at a winding speed of 400 m/min on a yarn bobbin at the winding zone. The process parameters used on false twist texturing machine is shown in Table 2.

Figure 3. Gloves developed from PLA.

The details regarding the knitting parameters of the fabrics are given in Table 3. Two different yarn linear densities (i.e. 150 dtex and 167 dtex), stitch densities (i.e. 70 and 80) and knit structures (i.e. single jersey and rib) were employed to produce eight different gloves structures as shown in Table 3.

Through this study, fabric samples were knitted on 13G JOMDA GD-D electronically controlled glove knitting machine using PLA textured yarns. Gloves developed from PLA yarn are shown in Figure 3. All samples were relaxed for one week in standard atmospheric conditions at a temperature range of 20±2 °C and a relative humidity of 65± 4 %.

The factors and their levels considered in this study are shown in Table 4. Yarn linear density (X_1), fabric structure (X_2) and stitch densities (X_3) has been nominated as factors. The levels of factor X_2 i.e. fabric structure is presented as 1 and 2 for single jersey and rib structure respectively.

Factors and responses with L_8 orthogonal array are given in Table 5.

Thermal conductivity of the gloves was tested by using Alambeta instrument whereas SDL sweating guard hotplate was utilized to investigate the thermal resistance of the knitted structures as per the standard testing method BS EN ISO 11092:2014. Water vapour permeability of the knitted structures were tested by using Permetest instrument according

Table 4. Factors and their levels

Factor	Code	Unit	Levels	
Yarn linear density	X_1	dtex	150	167
Fabric structure	X_2	N/A	1	2
Stitch densities	X_3	stitches/cm^2	70	80

Table 3. Physical properties of fabrics

No.	Yarn fineness (dtex)	Fabric structure	Stitch density (stitch/cm^2)	Loop length (cm)	Courses per cm	Wales per cm	Thickness (mm)	Mass per unit area (g/m^2)	Porosity (%)
1	150	Single jersey	70	0.5	10	7	1.25	158.56	91.13
2	150	Single jersey	80	0.5	10	8	1.29	162.33	90.24
3	150	Rib	70	0.5	10	7	1.36	172.14	89.55
4	150	Rib	80	0.5	10	8	1.39	174.24	89.10
5	167	Single jersey	70	0.5	10	7	1.28	160.13	90.67
6	167	Single jersey	80	0.5	10	8	1.30	164.11	90.17
7	167	Rib	70	0.5	10	7	1.39	176.95	89.48
8	167	Rib	80	0.5	10	8	1.42	178.45	89.05

Table 5. Factors and test results of responses

No.	X_1	X_2	X_3	Thermal conductivity (W/mK)	Thermal resistance (m^2K/W)	Relative water vapour permeability (%)	Air permeability (mm/s)	Overall moisture management capacity (OMMC)
1	150	1	70	0.0437	0.0277	52	198	0.7854
2	150	1	80	0.0429	0.0286	49	194	0.7456
3	150	2	70	0.0387	0.0330	46	190	0.4981
4	150	2	80	0.0372	0.0334	45	186	0.4764
5	167	1	70	0.0418	0.0283	51	195	0.6976
6	167	1	80	0.0412	0.0294	50	192	0.6567
7	167	2	70	0.0356	0.0348	45	189	0.4321
8	167	2	80	0.0347	0.0357	44	187	0.4287

to ISO 11092 standard method. SDL Atlas air permeability tester was utilized to determine the air permeability of the samples as per the standard testing method EN ISO 9237:1997. ASTM D-1777:2002 standard test method was utilized to measure the fabric thickness. Overall moisture management capacity of the fabric samples was examined by SDL Atlas moisture management tester according to AATCC 195 standard method. Five repetitions were conducted for the tests applied and the averages of the values were calculated.

Results and Discussion

The test results of the fabrics investigated are presented in Tables 5. Minitab®18 statistical software was employed to statistically analyze the test results. Table 6 represents the regression coefficients of the terms with their p-values.

The terms are considered significant with 95 % confidence if their p-values are less than 0.05. The regression coefficient with higher number demonstrates greater effect of representative term and vice versa. A negative (-) number demonstrates inverse relation of the response/output variable with the factor/input variable. It is clear from Table 6 that the factor, fabric structure (X_2) have significant effect on all the response variables, whereas the effect of factor, yarn linear density (X_1) is not significant on water vapour permeability and air permeability of the fabric samples investigated. Similarly the effect of factor, fabric stitch density (X_3) is significant on all response variables except on moisture management capacity of the fabrics. The interaction of factors X_1 and X_2 (X_1X_2) is also significant on thermal resistance of the fabrics as demonstrated in Table 6. The regression models containing the significant factors are presented in Table 7 for every output variable. The effect of factors on each response variable is separately discussed in the following sections.

Table 6. Regression coefficients for response variables

Terms	Thermal conductivity (W/mK)		Thermal resistance (m^2K/W)		Relative water vapour permeability (%)		Air permeability (mm/s)		Overall moisture management capacity	
	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value	Coeff.	p-value
Constant	0.039475	0.000*	0.031363	0.000*	47.750	0.000*	191.375	0.000*	0.59008	0.000*
X_1	-0.001150	0.002*	0.000687	0.003*	N/A	N/A	N/A	N/A	-0.03630	0.005*
X_2	-0.002925	0.000*	0.002863	0.000*	-2.750	0.000*	-3.375	0.001*	-0.13125	0.000*
X_3	-0.000475	0.034*	0.000413	0.012*	-0.750	0.030*	-1.625	0.014*	N/A	N/A
X_1X_2	N/A	N/A	0.000337	0.020*	N/A	N/A	N/A	N/A	N/A	N/A

(*) statistically significant terms with 95 % confidence level, (N/A) Terms were not estimated by Minitab.

Table 7. Regression models for fabric characteristics

Fabric characteristics	Regression models	R^2 (%)
Thermal conductivity (W/mK)	$0.07682 - 0.000135\ X_1 - 0.005850\ X_2 - 0.000095\ X_3$	99.11
Thermal resistance (m^2K/W)	$0.02265 - 0.000038\ X_1 - 0.00686\ X_2 + 0.000083\ X_3 + 0.000079\ X_1 \times X_2$	99.81
Relative water vapour permeability (%)	$67.25 - 5.500\ X_2 - 0.1500\ X_3$	96.30
Air permeability (mm/s)	$225.87 - 6.750\ X_2 - 0.3250\ X_3$	93.64
Overall moisture management capacity	$1.661 - 0.004271\ X_1 - 0.2625\ X_2$	98.43

Thermal Conductivity

Thermal conductivity is the transmittance of heat across a given area at a defined temperature rise per unit length. The effect of all three factors (X_1, X_2 and X_3) on thermal conductivity is found to be significant, because their p-value is lower than 0.05 as presented in Table 6.

Thermal conductivity results in Table 5 showed all the gloves knitted with single jersey structure have substantially greater thermal conductivity values than the gloves knitted with rib structure which may be attributed to the fact that the air percentage in the structure rises with higher thickness of the structure. As rib structure is thicker than single jersey structure, therefore allowing more air to be trapped inside the structure, hence presenting less thermal conductivity values than single jersey structure. It is distinguished fact that the thermal conductivity of structure is mainly dependent on fibre type and air entrapped in the structure as air is the least thermal conductive medium in comparison to all fibers (λ_{air}=0.025 W/mK).

The other two factors, i.e. yarn linear density (X_1) and stitch density (X_3) have inverse relation with thermal conductivity of the fabric. Lower yarn linear density (i.e. 150 dtex) and lower stitch density (i.e. 70 stitch/cm^2) resulted in higher thermal conductivity of the knitted fabrics. This could also be explained in a way that lower yarn linear density and lower stitch density resulted in less thickness of the fabric, therefore allowing less air to be trapped inside the fabric structure hence resulting in higher thermal conductivity of the fabrics.

Surface plot of thermal conductivity versus yarn linear density and fabric structure has been presented in Figure 4(a). In the surface plots, single jersey and rib structures has been replaced with numeric numbers 1 and 2 respectively. It can be noticed in Figure 4(a) that fabric thermal conductivity is maximum when yarn linear density is minimum and single jersey structure showed higher thermal conductivity than rib structure due to the reasons mentioned earlier. Similarly surface plot of thermal conductivity versus fabric structure and stitch density is presented in Figure 4(b) which demonstrates that lower stitch density of the fabrics resulted in higher thermal conductivity due to less air trapped inside the fabric structure and vice versa.

Regression model for thermal conductivity is presented in Table 7. The coefficient of determination of the regression model for thermal conductivity is 99.11 %.

Thermal Resistance

Thermal resistance determines the ability of a fabric to resist the heat flow and is measured by the ratio of fabric thickness to fabric thermal conductivity, so it seems obvious that thermal resistance have direct relation to fabric thickness and inverse relation with fabric thermal conductivity. The effect of all three factors (X_1, X_2 and X_3) on thermal resistance is found to be significant because their p-value is lower than 0.05 as shown in Table 6. Gloves knitted from rib structure were found to be more thermal resistant than single jersey structure as indicated by results presented in Table 5. This may be due to the fact that the thickness of rib structures is more than the thickness of single jersey structures as shown in Table 3.

The single jersey structure is less thermal resistant than rib structure which may be due to the reason that the density of the constituent yarns in single jersey structure is less hence the structure is more open, and perhaps trapping lesser percentage of air than rib structure, whereas rib structure appeared to be more thermal resistant maybe due to greater packing arrangement of yarns as packing density is recognized to have significant impact on thermal resistance. Therefore, for getting higher thermal resistance of gloves, a densely knitted structure will be preferred. These results are in good relation with existing findings from other researchers [10,13,14] in which most of them have related thermal resistance to fabric thickness.

The other two factors, i.e. yarn linear density (X_1) and stitch density (X_3) also have direct relation with thermal resistance of the fabric. Higher yarn linear density (i.e. 167

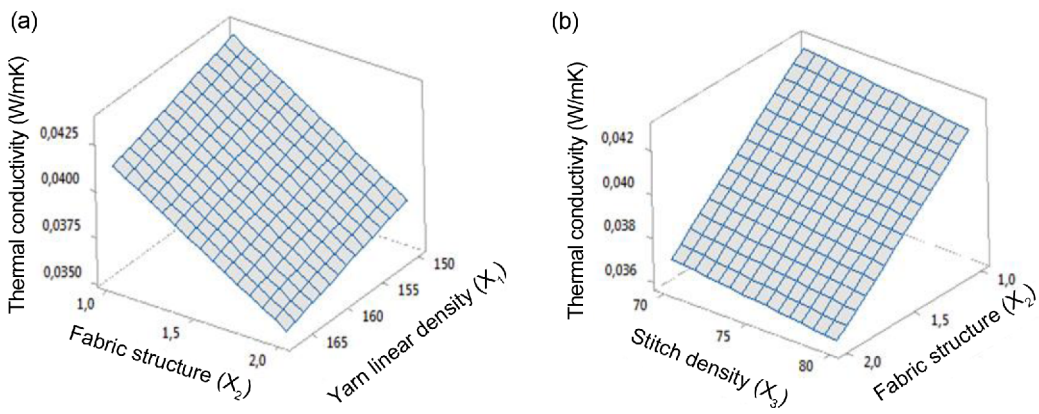

Figure 4. (a) Surface plot of thermal conductivity versus yarn linear density and fabric structure and (b) surface plot of thermal conductivity versus fabric structure and stitch density.

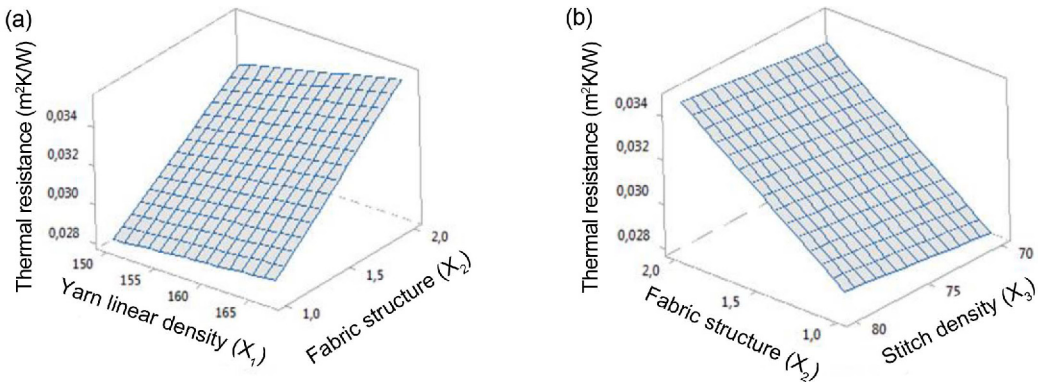

Figure 5. (a) Surface plot of thermal resistance versus yarn linear density and fabric structure and (b) surface plot of thermal resistance versus fabric structure and stitch density.

dtex) and higher stitch density (i.e. 80 stitch/cm^2) resulted in higher packing density of the fabric hence increasing the thermal resistance of the structures.

Surface plot of thermal resistance versus yarn linear density and fabric structure has been presented in Figure 5(a). As noticed in Figure 5(a) that fabric thermal resistance becomes higher once yarn linear density is maximum and rib structure showed higher thermal resistance than single jersey structure due to higher packing density of fibers which ultimately increased the thickness of the rib structure, hence presenting higher thermal resistance than single jersey structure. Similarly surface plot of fabric structure and stitch density versus thermal resistance is shown in Figure 5(b) which demonstrates that higher stitch density resulted in higher packing density of the fabric which ultimately increased thermal resistance due to more air trapped inside the fabric structure.

Regression model for thermal resistance is shown in Table 7. The coefficient of determination of the regression model for thermal resistance is 99.81 %.

Relative Water Vapour Permeability

The capability of a fabric to transfer water vapour through the fabric is known as water vapour permeability [14]. Gloves offering high water vapour permeability are considered to be more comfortable. From Table 5, it can be seen that gloves knitted with single jersey structure offer higher water vapour permeability values than gloves knitted with rib structure. The considerably dense and thick construction of the gloves with rib structure might have inhibited the vapour diffusion through the structure. As far as fabric structure in relation to vapour diffusion through the fabrics is concerned, it is seen that gloves knitted with rib structure presented lower water vapour permeability values than gloves knitted with single jersey structure. This is due to the fact that considerably thick and dense constructions of the gloves knitted with rib structure seem to prevent the water vapour transfer more than single jersey structure. Similar trends were seen by the other researchers [12-14]. This trend perceived may be described by the glove thickness and the density of constituent fibres in the glove structure.

Table 6 signifies that the effect of fabric structure (X_2) and stitch density (X_3) on vapour permeability is significant because their p-value is less than 0.05 however the effect of yarn linear density on vapour permeability is not significant. Stitch density also has inverse relation with the water vapour permeability%. Higher stitch density of the fabrics resulted in lower water vapour permeability as shown by the surface plot of water vapour permeability versus stitch density and fabric structure in Figure 6. This may be attributed to the reason that due to higher stitch density fabric structures became bulky and vapor diffusion has been stated to be lowest in bulky structures, and highest for fabrics with open structures [13].

Regression model for relative water vapour permeability is presented in Table 7. The coefficient of determination of the regression model for relative water vapour permeability is 96.30 %.

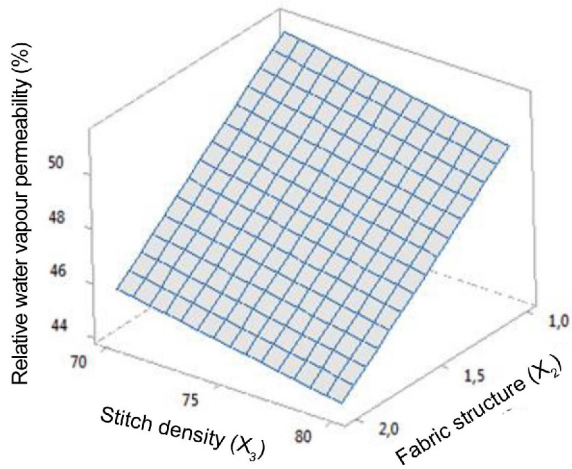

Figure 6. Surface plot of relative water vapour permeability versus stitch density and fabric structure.

Air Permeability

Air permeability is the air flow passing through a fabric under a given air pressure. As shown in Table 6, the effect of factors X_2 and X_3 on air permeability of the knitted structures is significant however the effect of factor X_1 is not significant. The air permeability of rib structures was considerably lesser to that of single-jersey structures. It might be due to greater packing density and higher fabric thickness of rib structures in comparison to single-jersey structures. It was also noticed that with an escalation in area density of knitted structures, air permeability of structures reduced quite significantly; therefore, an inverse relation was observed between area density and air permeability of knitted structures. However fabric structure was found to be more significant than yarn linear density in terms of air permeability of the knits investigated. Similar trends were also observed by other researchers such as [12,15]. Stitch density witnessed to have inverse relation with the air permeability of the structures investigated. Higher the stitch density, lower will be the air permeability of the structures. Surface plot of air permeability versus stitch density and fabric structure in Figure 7 demonstrates that single jersey structure and lower stitch density resulted in higher air permeability of the structures irrespective of the yarn linear density.

Regression model for air permeability is shown in Table 7. The coefficient of determination of the regression model for air permeability is 93.64 %.

Overall Moisture Management Capacity

Overall Moisture Management Capacity (OMMC) is an index to designate the capability of the fabric to manage the passage of liquid moisture. Moisture management tester comprises of two sensors that are positioned on both sides of samples investigated. Test liquid is fallen on top surface of the fabric which refers to inner side of the fabric that is in touch with the skin. The difference in electrical resistance of fabrics is recorded immediately. This device can categorize fabrics in view of moisture management properties in different categories. OMMC values of the fabrics are categorized with the grading scale given by the AATCC 195 standard test method as presented in Table 8.

It can be observed from the results in Table 5 that the OMMC value is highest for single jersey fabrics and lowest for rib fabrics. The OMMC values for single jersey structures were in the range of 0.6 to 0.8 which is categorized as "very good" whereas those of rib structures were in the range of 0.4 to 0.6 which is categorized as "good" according to AATCC 195 standard test method. This may be due to the fact that fabrics knitted with rib structure had more thickness and areal density as compared to samples knitted with single jersey structure, hence restricting the liquid moisture transport. Similar trend was also seen in the research carried out by Kumar and Das on moisture management behaviour of knitted fabrics [16]. For overall moisture management capacity of fabrics, yarn linear density (X_1) and fabric structure (X_2) were found to be significant as shown in Table 6, however fabric stitch density (X_3) was not statistically significant.

Surface plot of OMMC versus fabric structure and yarn linear density has been plotted in Figure 8 where it can be seen that higher yarn linear density resulted in lower OMMC values. This may be due to the reason that more bulkier

Table 8. Categories of OMMC values

No.	Category	Value
1	0 to 0.2	Very Poor
2	0.2 to 0.4	Poor
3	0.4 to 0.6	Good
4	0.6 to 0.8	Very Good
5	> 0.8	Excellent

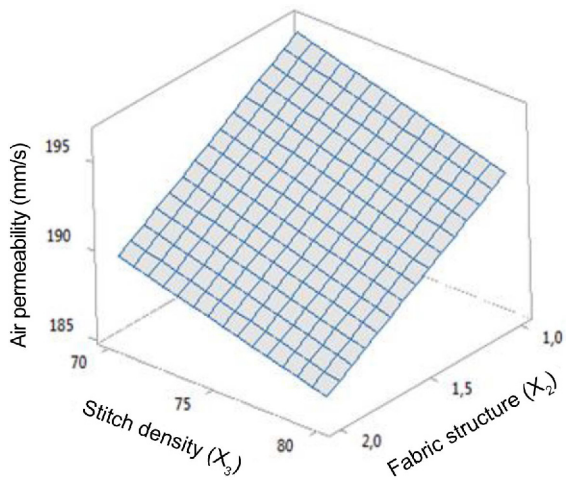

Figure 7. Surface plot of air permeability versus stitch density and fabric structure.

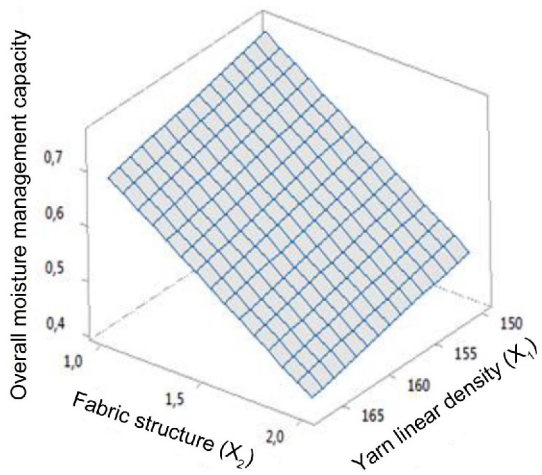

Figure 8. Surface plot of overall moisture management capacity versus yarn linear density and fabric structure.

fabrics with higher packing density and weight tends to be produced with higher yarn linear density, hence restricting the liquid moisture transport.

Regression model for OMMC of fabrics is presented in Table 7. The coefficient of determination of the regression model for OMMC is 98.43 %.

Conclusion

PLA is acknowledged to be sustainable and eco-friendly polymer with substantial commercial prospective as a textile fiber having superior wicking and moisture management properties than conventional oil based polymers therefore in this study it was aimed to develop biobased compostable gloves from PLA yarns and to develop regression models to predict their thermo-physiological comfort properties. Thermo-physiological comfort and moisture management properties of biobased gloves knitted from draw textured PLA yarns were investigated. Gloves were produced with different yarn linear densities, fabric structures and stitch densities. Yarn linear density (X_1), fabric structure (X_2) and stitch density (X_3) were taken as factors/input variables and their effect on different response variables such as thermal conductivity, thermal resistance, relative water vapour permeability, air permeability and OMMC of fabrics were investigated by using Minitab 18 statistical software. From the findings of this research, the following conclusions can be made.

Gloves knitted with single jersey structure have substantially greater thermal conductivity values than the gloves knitted with rib structure. The single jersey structure is less thermal resistant than rib structure which may be due to the reason that the density of the constituent yarns in single jersey structure is less hence the structure is more open, and perhaps trapping lesser percentage of air than rib structure, whereas rib structure appeared to be more thermal resistant maybe due to greater packing arrangement of yarns as packing density is recognized to have significant impact on thermal resistance. As far as fabric structure in relation to vapour diffusion through the fabrics is concerned, it is seen that gloves knitted with rib structure presented lower water vapour permeability values than gloves knitted with single jersey structure. The air permeability of rib structures was considerably lesser to that of single-jersey structures. Higher stitch density resulted in lower air permeability of the fabrics. It was observed that the OMMC value of the fabrics investigated is highest for single jersey fabrics and lowest for rib fabrics.

Statistical models were developed for thermal conductivity, thermal resistance, relative water vapour permeability, air permeability and OMMC of gloves knitted from PLA draw textured yarns. The coefficients of determinations (R^2 values) presented good estimation capability of the established regression models. Authors, as a part of future studies are currently working on the comparison of thermo-physiological properties of biobased gloves from PLA to that of petroleum based gloves such as PET. The outcomes of this research may be useful in determining suitable manufacturing requirements of PLA based gloves to accomplish precise thermo-physiological and moisture management properties.

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References

1. R. Guruprasad, A. Arputharaj, and S. Saxena, *J. Ind. Text.*, **45**, 405 (2015).
2. R. E. Drumright, P. R. Gruber, and D. E. Henton, *Adv. Mater.*, **12**, 1841 (2000).
3. O. Avinc and A. Khoddami, *Fibre Chem.*, **41**, 16 (2009).
4. T. Hussain, M. Tausif, and M. Ashraf, *J. Clean. Prod.*, **108**, 476 (2015).
5. A. Abdrabbo and A. F. Fotheringham, *J. Text. Inst.*, **104**, 28 (2013).
6. G. A. Baig and C. M. Carr, *J. Text. Inst.*, **106**, 111 (2015).
7. B. Bax, *Compos. Sci. Technol.*, **68**, 1601 (2008).
8. M. Awais, M. Tausif, F. Ahmad, A. Jabbar, and S. Ahmad, *J. Text. Inst.*, **106**, 354 (2015).
9. M. Ertekin and H. E. Kirtay, *J. Text. Inst.*, **107**, 1276 (2016).
10. S. Cimilli, B. U. Nergis, C. Candan, and M. Ozdemir, *Text. Res. J.*, **80**, 948 (2010).
11. Oglakcioglu and Marmarali, *Fibers Text. East. Eur.*, **15**, 94 (2007).
12. O. Demiryürek and D. Uysaltürk, *Text. Res. J.*, **83**, 1740 (2013).
13. R. R. V. Amber, C. A. Wilson, R. M. Laing, B. J. Lowe, and B. E. Niven, *Text. Res. J.*, **85**, 1269 (2014).
14. A. D. Gun, G. Alan, and A. S. Macit, *J. Text. Inst.*, **107**, 1112 (2016).
15. J. Abramavi, *Fibres Text. East. Eur.*, **18**, 84 (2010).
16. B. Kumar and A. Das, *Fiber. Polym.*, **15**, 625 (2014).
17. M. Maqsood, H. Tanveer, M. H. Malik, and Y. Nawab, *J. Text. Inst.,* **107**, 315 (2016).