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Development of biobased socks from sustainable polymer and statistical modeling of their thermo-physiological properties

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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 eco-friendly polymer with substantial commercial prospective as a textile fiber however, this polymer has not been investigated much in apparel applications. Therefore in this study it was aimed to develop biobased compostable socks from PLA draw textured melt spun yarns and to examine the effect of yarn linear density, fabric structure and stitch density on thermo-physiological characteristics of PLA based socks. 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 socks knitting. Single jersey and rib structures were produced with two different stitch densities to investigate their effect on thermal resistance, relative water vapour permeability, thermal conductivity, vertical wicking and air permeability of the socks. 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 socks to accomplish precise thermo-physiological properties.

1. Introduction

The physical properties and structure of Polylactic acid (PLA) has been the subject of multiple studies, indicating this polymer is equipped with substantial commercial prospective as a textile fiber. Contrary to oil based polymers, PLA is eco-friendly and sustainable polymer because it is derived from annually renewable resources such as corn; therefore, PLA is considered to be an environment friendly polymer as compared to conventional PET (polyethylene terephthalate) (Guruprasad et al., 2015). 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 (Drumright et al., 2000). Since the quantity of corn used up in the manufacturing of PLA fibers is not more than 0.02% of the entire corn production in the world therefore, PLA production from corn will not consequence in a food disaster (Avinc and Khoddami, 2009). PLA needs 25–55% less fossil resources in its production as compared to the production of oil-based polymers (Hussain et al., 2015). 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 (Abdrabbo and Fotheringham, 2013) (Baig and Carr, 2015). 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 (Bax, 2008). Despite of all these advantages of PLA over petroleum based polymers this polymer has not been used much in apparel applications.

Gun et al. investigated the physical and dimensional characteristics of socks developed from reclaimed fibers and observed that reclaimed fiber socks exhibit higher pilling propensity than virgin fibers (Gun et al., 2014). Amber et al. studied the relative effects of wool and acrylic fibers, yarn type (high and low twist) and fabric type on moisture transfer properties of socks and found that the packing density within the fabrics affect the most on comfort characteristics of fabrics (Van Amber et al., 2014). Cimilli et al. 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 (Cimilli et al., 2010a,b). Oglakcioglu and Marmarali

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examined thermo-physiological characteristics of different knitted structures and observed that rib and interlock knit structures presented greater thermal resistance than single jersey structures whereas single-jersey knit structures showed higher water vapour permeability (Oglakcioglu and Marmarali, 2007). Demeryurik studied the effect different fiber types and their structure on thermo-physiological characteristics of different fabrics and found that distinctive fibers enhanced the thermo-physiological characteristics of fabrics (Demiryürek and Uysaltürk, 2013).

Majority of the studies (Prahsarn et al., 2005) (Abramavi, 2010) (Psikuta et al., 2011) (Purvis and Tunstall, 2004) reported in the literature has concentrated on the examination of thermal and comfort properties of socks knitted from petroleum based polymers, such as poly(ethylene terephthalate) (PET), PET/elastane and PET/polyamide however there isn't any literature available on the examination of thermo-physiological comfort properties of socks knitted from biobased polymers such as polylactides. The thermo-physiological characteristics of knitted socks 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 resistance, relative water vapour permeability, thermal conductivity, vertical wicking and air permeability of socks produced from PLA draw textured melt spun yarns. 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 socks to accomplish precise thermo-physiological properties.

2. Materials and methods

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 h. 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. 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.

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 Fig. 1.

Table 1
Yarn characteristics 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

After spinning, PLA-POY multifilament yarns were draw textured on Barmag AFK2 false twist texturing machine as shown in Fig. 2.

Texturing of multifilament yarns is done in order to obtain similar properties to that of 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 twisting zone which consisted of a number of ceramic discs. The twisted yarn was 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.

The details regarding the knitting parameters of the socks are given in Table 3. Two different yarn linear densities (i.e. 150 dtex and 167 dtex), stitch densities (i.e. 56 and 64) and knit structures (i.e. single jersey and rib) were employed to produce eight different socks structures as shown in Table 3.

Socks from PLA draw textured yarns were knitted on E9 gauge, FDS Model Future 5C single cylinder socks knitting machine having 120 needles with 4 inches diameter of the cylinder. Knitting structures investigated in this study and sock developed from PLA are shown in Fig. 3. The socks were knitted at the same knitting parameters (i.e. the loop length, number of needles and cylinder diameter for all the socks samples was kept constant). Sock samples were conditioned for seven days under standard atmospheric conditions.

The factors and their levels used in this research are shown in

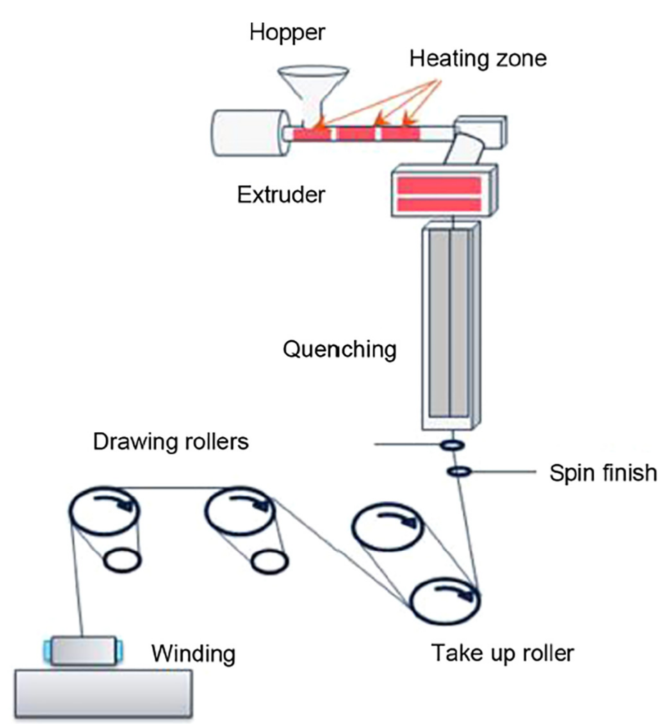

Fig. 1. Different zones of melt spinning machine.