Investigation of the Thermal and Physical Properties of Fabrics Produced by Metallic-Polymer Hybrid Yarns

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I. INTRODUCTION

Majority of the smart devices contain touch screens and the majority of them are based on capacitance and conductivity. This type of touch screens are developed by utilizing a matrix of rows and columns of conductive electrodes and small current is provided to electrodes to produce an even electrostatic field[1]. However, electrically insulating materials such as textile fabrics, cannot actuate touch screens as these types of materials are incapable of changing the electrostatic field.

This behavior of touchscreens have led to huge problems during winter season because people wear gloves to get warmth and the thickness of the textile material does not allow to actuate the touchscreen, because it reduces the conductance[2]. Due to this problem touch sensitive glove designs are invented. Since, the thumb and the index fingers are the most commonly used fingers to operate mobile phones, some researches have been done to check the effectiveness of gloves with conductive yarns in thumbs and index fingers[2]. Major drawback when using conductive yarns directly on the fingertips would be that it minimizes the main function of a glove. These added conductive yarns are good heat conductors, so they will allow heat to penetrate through the gloves. Particular type of glove will use one out of comfort, touch sensitivity, thermal resistance, fit to body as their major feature while compromising other properties[3], [4].

As a solution for this, copper coated nylon yarn textured using polyester yarn will be used to achieve the thermal and physical properties desired for a fabric, used to produce thermal protective winter gloves. Mostly for existing touch screen gloves, copper or silver coated nylon yarns are used as the conductive yarn[5]. These metals are coated on the nylon yarn with a polymeric career[6]. These yarns show high thermal conductivity as well as electrical conductivity. So, by using these types of yarns will decrease the effectiveness of the glove as a thermal protective clothing. Instead of using a metal coated yarn directly, metal coated yarn covered with a polyester yarn using hollow spindle spinning or air texturing method. Due to the polyester covering the thermal conductivity of the metallic yarn will be reduced. A touch screen glove produced from such a yarn is expected to provide the desired function while maintaining the thermal resistance of the glove. And by using air texturing process, air pockets are expected to be formed between the two yarns[7]. Hence, this project focuses on producing polymer/metallic composite yarns using hollow spindle spinning and air jet texturing, and then evaluating the thermal and physical properties of fabrics produced using those yarns.

II. LITERATURE REVIEW, MATERIALS AND METHODS

A. *Literature review*

Existing touchscreen gloves encounter issues of discomfort and low breathability. The "U|R Powered" technology, commonly utilized, involves conductive leather or fabric combined with a liner fabric. A pattern of conductive polymer is applied via spraying or screen printing [6]. Conductance ranges from 2x10-3Ω-1 to 2x10-6Ω-1 per unit area [6]. This conductive layer combines with other fabrics to create glove fingertips compatible with touchscreens. For instance, The North Face® markets Etip™ gloves using this approach. Some gloves incorporate micro conductive yarn sewn into the fingertips, often with separate Thinsulate™ Insulation for warmth [6]. However, these gloves sacrifice breathability, leading to discomfort and a chilly sensation when wet. Drying time is also extended after moisture exposure.

Alternatively, gloves can be coated with a uniform conductive polymer. This involves mixing tiny metal particles with polymers like polyethylene, polypropylene, or polyurethane. The mixture is then applied to the glove, enabling touchscreen use through conductivity [8]. Examples of this include PIP G-TEK® 33-GT125, T-ROC, and MIDAS gloves [9]–[11]. However, the coating fills air gaps, completely blocking airflow and causing discomfort. These polymer-coated gloves find extensive use in industrial contexts.

Embroidered conductive yarns within fabric offer another option, though accuracy diminishes with yarn diameter [6]. Thus, these gloves are less popular than polymer-coated counterparts.

B. *Materials*

Initially, the core yarn choice was metal-coated nylon (copper), complemented by an effect yarn of polyester. Given the inherent brittleness and limited flexibility of pure metal yarns, effectively achieving overfeeding during the air-jet texturing process posed challenges. To address this, a more flexible metal-coated yarn was chosen, allowing successful overfeeding. Moreover, for the effect yarn, a thermoplastic option like polyester was favored, offering potential improvements in loop stability through heat setting.

Furthermore, specifications of the raw materials are provided for reference: the Silver Coated Polyester Yarn (Chemical Vapor Deposition) has a yarn count of 33 denier and 7 filaments, with a resistivity of 3.7 Ωm, while the Conventional Multifilament Polyester Yarn (POY) has a yarn count of 150 denier and 48 filaments.

C. Machines

The SSM DP5 air-jet texturing machine was employed for this purpose. Here, conductive yarn served as the core, and conventional polyester yarn was used as the effect.

SSM DP3-C machine was used to produce Air-Intermingled yarn.

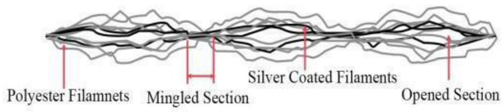

Figure 1 - Air-Intermingled Yarn

D. Testing

After producing the fabric, it was subjected to thermal and physical property tests, and the obtained data were critically analyzed. When considering the thermal conductivity test, a guarded hot plate will be used to obtain the thermal conductivity across the fabric. Since the metallic polymer hybrid yarns are intended to use as the yarns for touch-compatible winter gloves, they need good thermal insulation. After producing the textured yarns, the first single jersey fabric will be produced using a flatbed knitting machine.

- i *Thermal Conductivity*
- ii *Air Permeability*
- iii *Electrical Conductivity*

III. RESULTS AND DISCUSSION

In this study, the developed yarn was analyzed in different ways. The count of the developed yarn is 387 D, and it has 103 filaments in the final yarn. In addition, the developed fabric has a GSM value, and the value is 310 Furthermore, the distance between the two intermingle points is 23mm and filaments which are in between the mingled points open up and provide more air gaps within the filament. Hence the improved thermal insulation property is expected to be achieved from this yarn. Furthermore, the developed yarn is observed under the microscope 10x zoom and following images show the structure of the yarn under 10X zoom.

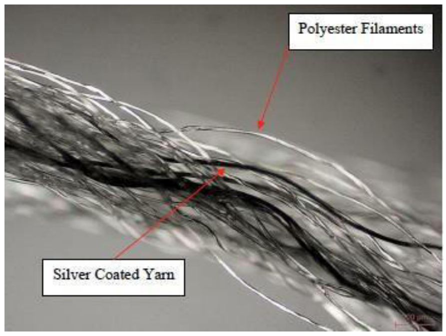

Figure 2 - Microscopic image of the Air-Intermingled Yarn

A. Electrical Conductivity

Initially, the electrical conductivity of the single covered yarn is measured, and it gives zero electrical conductivity. Here, the conductive yarn is used as core yarn, hence, it is not exposed to the outside, hence the yarn surface does not show any conductive value. Therefore, the air intermingling process is used to develop the metallic polymer hybrid yarn and the conductivity of that yarn was measured.

Since the conductivity achieved through a coating, it can be come off from the surface upon washing. Therefore, the durability of the electrically conductive coating was tested. According to the result, the conductivity of the fabric decreased upon washing, therefore, it shows that the durability of the conductive coating reduces with the increases of number of washing cycles. Therefore, touch screen compatibility is expected to be reduced upon washing. Furthermore, the accuracy of the touchscreen point may be reduced with the reduction of conductive coating.

B. Air Permeability

Since the yarns are intended to be used to produce winter gloves with touch screen compatibility, they should contain some physical properties as well. There are various properties of winter gloves that should maintain. As a physical property test air permeability test was carried out using the EN ISO 9237 test standard. The testing rate of airflow passing through a given area of the fabric was tested. According to the standard, the test area was 20cm ^{2}and air permeability values were given in the dm ^{3}/s unit.

Since the air intermingling process introduces some texture into the polyester filament yarn, the final yarn gets bulkier. To obtain the effect of the air intermingle process on air permeability, the fabric was developed using only polyester filament yarn. Using two 150D count yarns single jersey knitted fabric was produced. Then air permeability test was carried out for that fabric according to the EN ISO 9237 test standard method.

According to the test results, the air permeability of the polyester fabric is comparatively lower than the fabric produced from air-intermingled yarn. The air intermingle process introduces intermingle points and opened sections throughout the yarns. This textured effect will increase the bulkiness of the yarn. When a fabric is produced using the air intermingle yarn, that fabric will have more empty spaces compared to the normal polyester fabric. These empty spaces will allow air to flow through and will increase the air permeability.

IV. CONCLUSION

TABLE 1
ELECTRICAL CONDUCTIVITY TEST RESULTS

Distance between Electrodes (mm)	R_1 (Ω)	R_2 (Ω)	R_1/R_2	K	ρ (Ωcm)
60	388.13	121.96	3.18	0.286	0.138
40	294.95	79.65	3.70	0.303	0.148
20	200.40	50.77	3.94	0.310	0.196

Electrical conductivity, it can be clearly seen that when a conductive yarn is used as core yarn in the air permeability process, the final yarn has a considerable amount of electrical conductivity. But as the core yarn silver-coated nylon yarn is used, this silver coating can be worn out with the wash cycles. So, the washing durability of the winter glove is low. But since the yarns are used to produce winter gloves, and they do not need to wash regularly like apparel, washing durability is not a major property.

TABLE 2
AIR PERMEABILITY VALUES OF FABRIC PRODUCED USING AIR INTERMINGLING YARN

Sample No	1	2	3	Average
Air Permeability (dm ^{3}/s)	0.9198	0.9323	0.9267	0.9265

TABLE 3
AIR PERMEABILITY VALUES OF THE FABRIC PRODUCED USING NORMAL YARNS

Sample No	1	2	3	Average
Air Permeability (dm ^{3}/s)	0.6917	0.6928	0.6942	0.6929

Winter gloves need to have good thermal resistivity while maintaining electrical conductivity and air permeability. The fabric produces from air intermingle yarns shows good air permeability compared to conventional polyester fabric. This confirms that the air intermingles process increases the empty spaces within the yarn. So, the air permeability will be increased. The thermal conductivity of the fabric is low. This happens because the air intermingles process increases the empty spaces between the yarn. Since air has lower thermal conductivity than yarn, the total thermal conductivity of the fabric decreases. Since the fabric is intended to use as touch-compatible glove fabric they have to have good abrasion resistance. The air intermingle yarn fabric has good abrasion properties as well. According to EN 338:2016, it has level 4 abrasion resistance.

The thermal conductivity evaluation was conducted using the guarded hot plate method. The measurements yielded significant data points: the steady-state temperature of the cooling plate was recorded at 43°C, while the heating plate maintained a steady state temperature of 49°C. The cooling rate observed during the test was 0.005479°C/s. The resultant thermal conductivity value of the fabric was determined to be 0.085198 $Wm^{-1}K^{-1}$. These findings collectively contribute to a comprehensive understanding of the fabric's thermal performance and its suitability for the intended application.

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