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ANALYSIS OF THERMAL BEHAVIOR FOR A POLYESTER FABRIC WATERPROOF BREATHABLE LAMINATED, USING SKIN MODEL BASED ON SENSOR

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The paper presents an analysis of the thermal behavior of a woven polyester structure, laminated with waterproof breathable polyurethane film, using skin model. The skin model depends on sweating guarded hotplate [1, 2] that describes the sensorial skin behavior [3]. For evaluating the thermal behavior for polyester fabric have been performed tests in controlled environment (air velocity, temperature, humidity) by using thermal hotplate for 1 hour. Thermal comfort is an important environmental factor that can indicate the parameters for quality of life and work. For the skin model were performed tests in controlled environment humidity 65% and by varying the thermal sensor values, in the climatic chamber, between 0 and 10 Celsius degree. The values received from sensor, such as REF (evaporative resistance for fabric), skin temperature, relative humidity (RH), air velocity and ambient temperature, have been analyzed using the program MATLAB.

Keywords: thermal, sensor, skin model, MATLAB, humidity, temperature

1. Introduction

The material, treated with waterproof breathable polyurethane, is useful in the fabrication of tenting, rainwear and garments with waterproofness and breathability requirements [4].

The water vapor is transmitted through the fabric by absorption, transmission, desorption; diffusion; absorption and transmission or convection.

The coating, made by using solid chemicals, influence the water vapor transmission and will generate chemical diffusion. For fabric, the hydrophilic component (amorphous regions) attracts the moisture and helps in humidity transfer, and the hydrophobic components help to resist to the water drops penetration [5]. The waterproof breathable properties depend by number of layers used for lamination, thickness of the layer, temperature and pressure used in coating process.

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The waterproof/breathable materials can be quantified by using hydrostatic head method, moisture vapor transmission rate (MVTR) and resistance to evaporative heat transfer (RET) [6]. In a cold place with temperature ranges from -5^0 C to -50^0 C, a high resistivity of heat is required in the same way with a breathable characteristic of fabric [7]. Protective clothing with both characteristics waterproof and breathable helps wearers in many unfriendly climatic conditions.

In this paper, we present experimental results obtained for behavior simulation, in the bioclimatic room, of the breathable textiles, obtained by polyurethane (PU) lamination. In order to obtain the response accuracy of the skin model, for the case of wearing the textile material covered with polyurethane foam, the parameters (temperature, air velocity, humidity) of the microclimate chamber have varied.

2. Related work

For evaluate the comfort performance of materials used in wearable structures (clothing) are appreciate the sensations such as fit, breathable and thermal and each one are contributing around 10% of the total comfort variance [8]. The comfort performance of the garment is important for protective equipment, sport articles and for the usual clothing [9].

Another advanced method for measure the thermal and water vapor resistance of the clothes is the use thermal mannequin that allows simulating the heat exchange between the human and the environment [10]. For example, in simulation Newton thermal mannequin [11] allows heat loss evaluation by using skin temperature in correlation with ambient temperature and humidity. Newton thermal mannequin allows through, RadTherm software, user inputs such as metabolism, respiratory volume and frequency and simulation time-step.

Fig. 1. Newton thermal mannequin [10]

3. Experimental Part

The experimental part consists in tests for skin modeling by using hotplate and stability test chamber Lunaire from Measurement Technologies US and software ThermDac (Fig. 2).

Fig. 2. Skin model testing – Lunaire Measurement Technologies US

The climatic chamber test allows the following work conditions:

- The heating of the air, in the bioclimatic room, was established, using recirculated air by Incoloy-sheathed tubular electric heaters;
- The cooling air is achieved by recirculated the air through refrigerated cooling coil;
- Humidification of chamber air has been achieved using a water vapour injection generated by a Vapor-Flo II Humidity Generator. The generator consists in a stainless-steel water tank where water was heated by an electric immersion heater;
- The air circulation was generated by centrifugal blower wheel, driven by an externally mounted motor;
- The temperature conditions have been controlled by a Partlow 1160+ Controller, which use an RTD sensor for temperature measurement;
- The humidity conditions have been controlled by a Partlow 1160+ Humidity Controller, which use a capacitive humidity sensor for humidity measurement (Fig. 3).

Fig. 3. Capacitive humidity sensor

The controller 1160+ allows one universal input for temperature/humidity and time proportioned control for heat or humidity (Fig. 4).

3.a. 1160+ temperature controller

3.b. 1160+ humidity controller

Fig. 4. 1160+ Controllers

The outputs from 1160+ are connected to a logical control board (LCB) which allows control for all system conditions using integrated input signal conditioning and triac outputs. The LCB is mounted on main control panel (Fig. 5).

Fig. 5. Main control panel (testing conditions: H=65%, T=0˚ C

For testing the textile surface on skin model hotplate were used as basic parameters (Fig. 5):

- environment humidity H=65;
- temperature T=0˚ C;
- hotplate temperature T=35˚C.

In the Fig. 6 is presented the hotplate calibration in ThermoDac software for simulate the human skin temperature, thermal resistance and vapor permeability of textiles structures (Fig. 6).

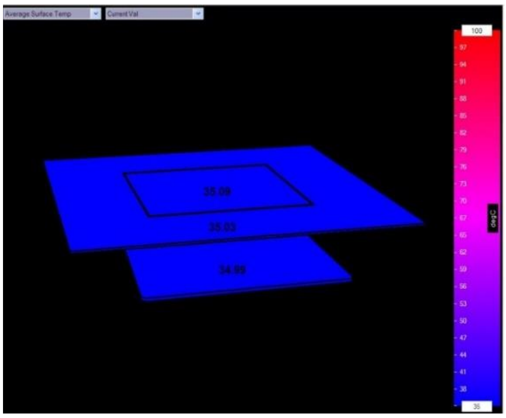

Fig. 6. Hotplate calibration

The software record data values from sensors in database and generates the charts for skin model evaporative resistance (RET), ambient temperature, ambient relative humidity and air velocity (Fig. 7).

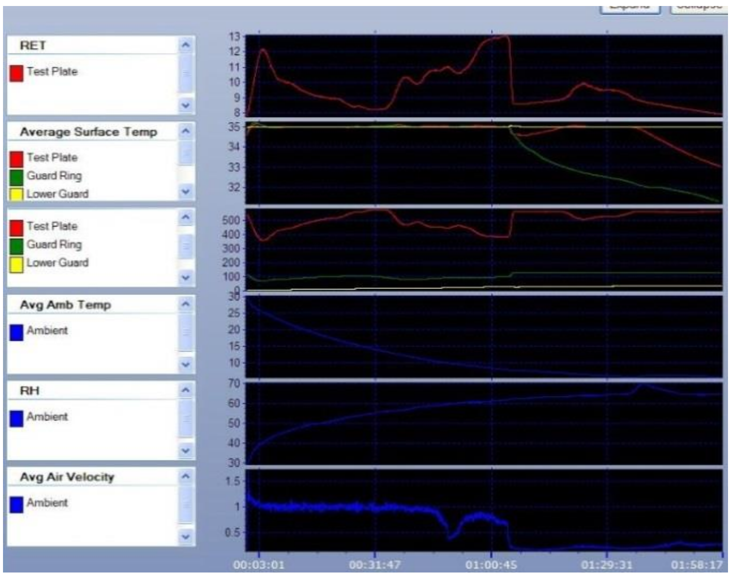

Fig. 7. Charts for parameters values recorded

The evaporative resistance for fabric (REF) has been calculated by using math formula (1):

$$R_{et} = \frac{(P_{sat} - P_{amb})}{Q/A} \quad (1)$$

where:

$$P_{sat} = 133.3 \cdot 10^{\left[8.10765 - \left(\frac{1750.29}{235 + T_{skin}}\right)\right]} \quad (2)$$

$$P_{amb} = RH \cdot 133.3 \cdot 10^{\left[8.10765-\left(\frac{1750.29}{235+T_{amb}}\right)\right]} \quad (3)$$

$$R_{ef} = (R_{et} - R_{et0}) \quad (4)$$

where:
P_{sat}=Saturation vapour pressure (Pa);
P_{amb}=Ambiant vapour pressure (Pa);
T_{skin}=Skin temperature (˚C);
T_{amb}=Ambient temperature (˚C);
RH=Ambient Relative Humidity (%);
R_{et}=Thermal resistance (m^2 ·˚C)/W;
R_{ef} (REF) =Fabric evaporative Thermal resistance (m^2 ·˚C)/W;
R_{et0}=bare plate resistance (m^2 ·˚C)/W;
R_{et0}=5.63 m^2 ·˚C;
Q/A=Area weighted Heat Flux (W/m^2);
Q=heat flux (W);
A=skin model area (m^2);
V_{air}=air velocity (m/sec).

4. Results and Discussion

The numerical values received from sensors, for RET (evaporative resistance for fabric), skin temperature, relative humidity, air velocity and ambient temperature, have been analysed by using MATLAB (Figs. 8-11).

From skin temperature representation in function of evaporative material resistance (REF) and humidity (Figs. 8, 9), it is evident that maximum value for skin temperature is obtained in conditions of high relative humidity value (70%) and low values for evaporative resistance.

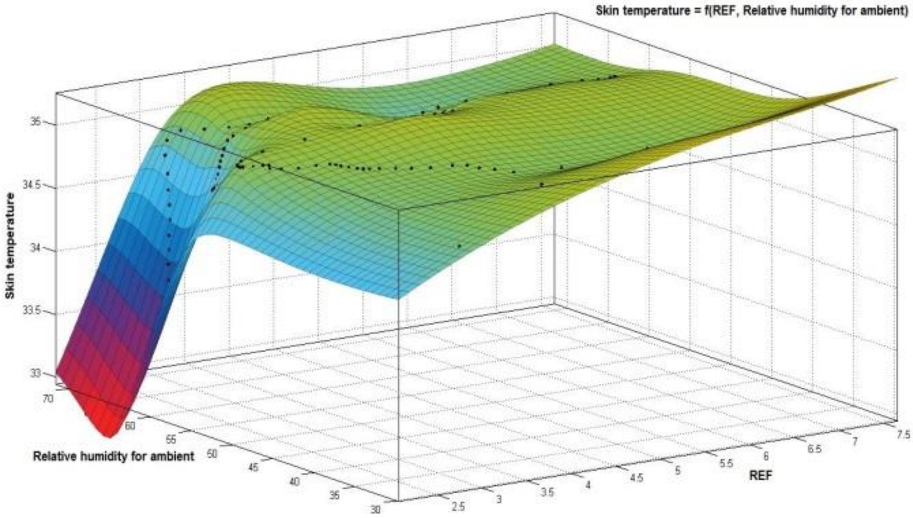

Fig. 8. Skin temperature=f(REF, ambiant humidity)

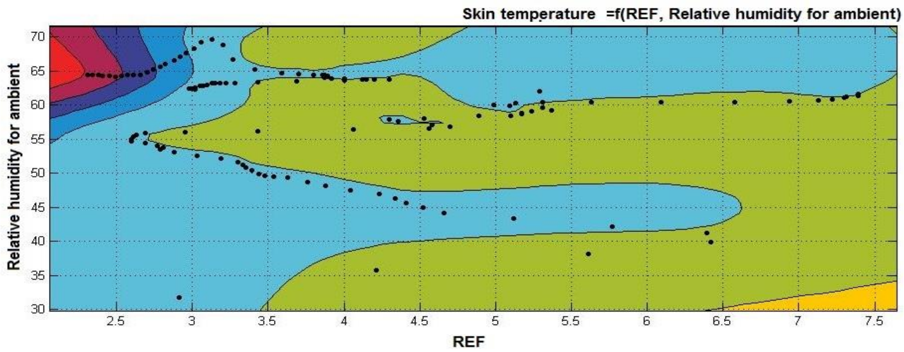

Fig. 9. Skin temperature – 2D mapping in function of relative humidity and fabric evaporative resistance

The skin temperature in function of the bioclimatic chamber temperature and air velocity (Figs. 10 and 11) shows that skin temperature is in strong dependence by ambient temperature. The air velocity does not has a signifiant influence on the skin temperature when the ambient temperature vary in the range [0-10^0 C].

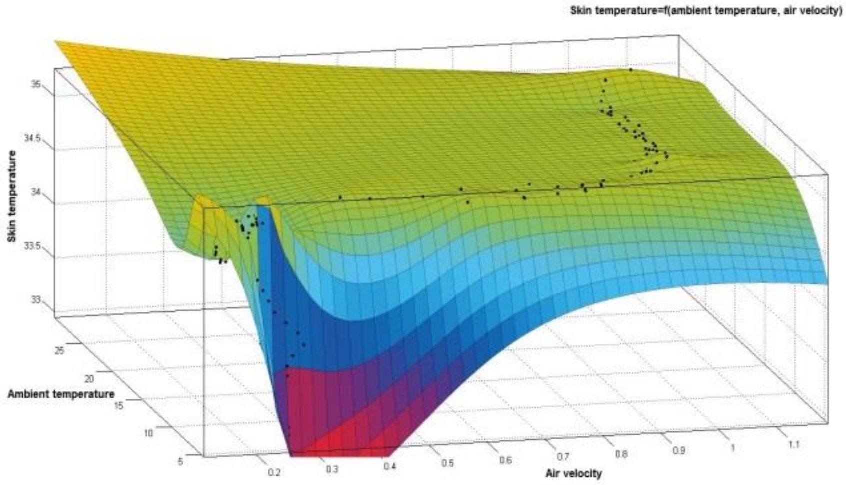

Fig. 10. Skin temperature=f(ambient temperature, air velocity)

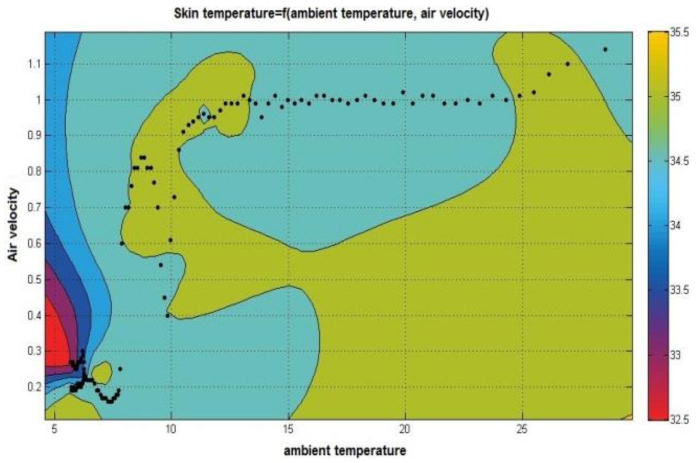

Fig. 11. Skin temperature- 2D mapping in function of ambient temperature and air velocity

By analyzing the covariance cov(T_{skin}, REF) (5, 6) we can conclude that between skin model temperature and fabric temperature it is a dependence because temperature from skin is transferred to the fabric layer. Also between temperature of the skin and humidity it is an inverse dependence cov(T_{skin}, RH) (7, 8).

$$\boldsymbol{cov(T_{skin}, REF)} = \begin{vmatrix} \mathbf{0.2336} & \mathbf{0.3090} \\ \mathbf{0.3090} & \mathbf{1.6899} \end{vmatrix} \tag{5}$$

$$cov(T_{skin}, REF)_{1,2} = cov(T_{skin}, REF)_{2,1} = 0.3090 \tag{6}$$

$$\boldsymbol{cov(T_{skin}, RH)} = \begin{vmatrix} \mathbf{0.2336} & \mathbf{-1.3980} \\ \mathbf{-1.3980} & \mathbf{58.9855} \end{vmatrix} \tag{7}$$

$$cov(T_{skin}, RH)_{1,2} = cov(T_{skin}, RH)_{2,1} = -1.3980 \quad (8)$$

The temperature values for human skin and humidity values are in invers report (humidity increasing at 0-10^{0}C) will generate a skin temperature reduction. By analyzing the covariance cov(T_{skin}, T_{amb}) between skin temperature and ambient temperature is a direct correlation and the ambient temperature can influence the skin temperature (9, 10).

$$\boldsymbol{cov(T_{skin}, T_{amb}) = \begin{vmatrix} 0.2336 & 1.1120 \\ 1.1120 & 36.1430 \end{vmatrix}} \quad (9)$$

$$cov(T_{skin}, T_{amb})_{1,2} = cov(T_{skin}, T_{amb})_{2,1} = 1.1120 \quad (10)$$

5. Conclusions

In this paper have been tested textile materials laminated with polyurethane foam and simulated their behavior to humidity increased (65%) under conditions of low ambient temperature (0-10^0 C).

In our research, we studied the behavior of the PU laminated textile for the protective equipment behavior. For difficult environment condition (0^0 C) and high humidity (65%) it important to maintain the vapor transport from skin to outside and not inverse direction. For these materials, it was performed a simulation in the bioclimatic room and the results have been interpreted and modelled by MATLAB.

The human thermoregulatory system controlled by hypothalamus is a controller for human body, in order to obtain a constant body temperature by cooling effect by thermolysis – obtained through sweat glands functioning, or warming effect by thermogenesis.

In condition of 0^{0}C, the sweat glands will function at low parameters and the controller will seek to maintain a constant temperature by avoiding the temperature waste. A waterproof layer integrated as first layer that comes in contact with outside environment, on a garment at 0^{0}C, will act as an insulator barrier and will not allow the wetting of the cloth layers.

In the smart materials design for protective equipment, it is very important to compose the structure layer by layer, in order to obtain a cooling or warming system for human body in difficult environment conditions.

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