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Guidelines for measuring thermal resistance on thermal Foot Manikin

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ABSTRACT

This study aims to optimize the factors affecting thermal resistance (R_{ct}) test on Thermal Foot Manikin (TFM). There are two types of testing on Thermal Manikin (nude and clothed manikin). Initial thermal resistance (R_{ct0}) is measured on both nude and clothed TFM. Clothed TFM is using mercerized cotton socks. Thermal resistance (R_{ct}) is evaluated for four types of woven compression bandages (WCBs). All bandage types were applied at extension ranges 10–80%, using both two- and three-layers bandaging. Moreover all samples were measured on three levels of ambient conditions (T: 20 ± 2 °C, RH: 65 ± 5%), (T: 22 ± 2 °C, RH: 65 ± 5%), (T: 20 ± 2 °C, RH: 50 ± 5%). The main factors affecting thermal resistance test are the temperature difference (ΔT) between ambient conditions and skin, yarns material, fabric structure (woven, knitted), thickness, weight per unit area, number of fabric and air layers. Obtained results of R_{ct0} and R_{ct} confirmed that clothed TFM is more accurate due to more stabilization and less effect of air convection.

Selection and peer-review under responsibility of the scientific committee of the 4th International Conference on Natural Fibers – Smart Sustainable Materials.

1. Introduction

Thermal manikins are devices by means of which it is possible to simulate heat exchange between the human and the environment [1]. The thermal resistance of fabrics is a primary determinant of body heat loss in cold environments. Generally, high thermal resistance values of the clothing are required to maintain the body under thermal equilibrium conditions. In hot environments or at high activity levels, evaporation of sweat becomes an important avenue of body heat loss and fabrics must allow water vapor to escape in time to maintain the relative humidity between the skin and the first layer of clothing about 50% [2–5]. There are six primary factors that must be approach when defining conditions for thermal comfort. These factors can be classified in two classes: measurable factors and personal factors. The measurable factors include: the air temperature, air velocity, radiant temperature and relative humidity. The personal factors include: activity level and clothing insulation [6,7]. WCBs and socks as porous materials should provide both the safety and thermal comfort of human beings, especially patients. WCBs aim to provide graduated compression to the lower limb from the ankle to the knee in order to improve venous return, accelerate venous flow, reduce venous reflux by realignment of valves, improve venous pump action, and to reduce oedema [8,9]. The main aim of this research is to introduce guidelines and recommendations for measuring thermal resistance on TFM dealing with the heat transfer conditions as illustrated in Fig. 1 [10,11].

2. Experimental work

2.1. Materials

Experimental samples consist of four WCBs as following: 100% bleached cotton, cotton/polyamide/polyurethane (CO-PA-PU), viscose/polyamide (VI-PA), and viscose/lycra (VI-LY) bandages, as shown in Fig. 2. All employed bandages' structures based on plain weave. Yarns' fineness and density are different depending on the construction and properties of the required end-uses.

2.2. Thermal Foot Manikin description

The measuring unit (MU) of Foot Manikin which is a part of origin Thermal Sweating Foot Manikin System [12] was used for measurement of thermal resistance only. The length of MU along x-axis is 265 mm whereas z-axis is 270 mm. The unit consists of 13 seg-

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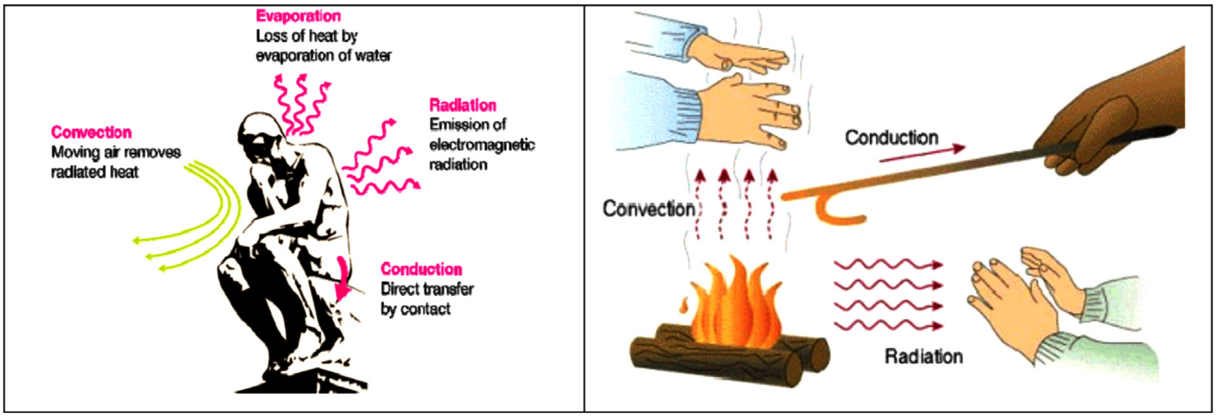


Fig. 1. Heat transfer over the body [10,11].

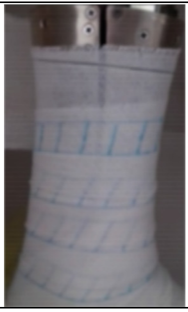
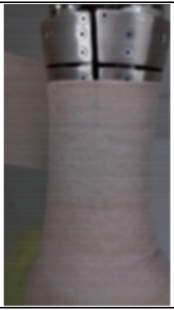
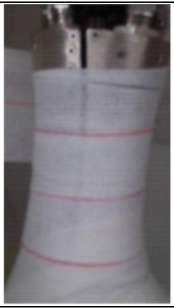
			
a) 100% Cotton bandage Warp density: 8 ends/cm Weft density: 15 picks/cm Warp count: Cotton, 20x2 tex, 1200 turns/m Weft count: Cotton, 75 tex, OE yarn. Fabric weight: 210.25 g/m^2 Fabric thickness: 1.06 mm	**b) CO-PA-PU (78-16-6%)** Warp density: 11 ends/cm Weft density: 18 picks/cm Warp count: Cotton, 10x2 tex / Polyamide, 7.8 tex / Polyurethane, 42.5 tex. Weft count: Cotton, 36.9 tex. Weight: 236.48 g/m^2 Thickness: 1.09 mm	**c) VI-PA (56 – 44%)** Warp density: 12 ends/cm Weft density: 14 picks/cm Warp count: Viscose, 16.5 tex, OE yarn / Polyamide – 7.8 tex Weft count: Viscose, 16.5 tex, OE yarn. Weight: 83.34 g/m^2 Thickness: 0.91 mm	**d) VI-LY (94 - 6%)** Warp density: 14 ends/cm Weft density: 38 picks/cm Warp count: Viscose, 8x2 tex / Lycra, 36 tex. Weft count: Viscose, 12 tex, OE yarn. Weight: 219.54 g/m^2 Thickness: 1.01 mm

Fig. 2. Parameters and application of experimental samples on nude TFM.

ments all made of silver. There are 30 heaters on the MU, at least 2 up to 4 for each segment, depending on the segment area. Each segment can be separately heated, turned-off, or individually controlled by special software. The range of controlled temperatures were set at ±0.5 °C.

Initial thermal resistance is measured on both nude and clothed TFM before each measurement of thermal resistance (R_{ct}) [13]. Moreover all samples were measured on three levels of ambient conditions (T: 20 ± 2 °C, RH: 65 ± 5%), (T: 22 ± 2 °C, RH: 65 ± 5%), (T: 20 ± 2 °C, RH: 50 ± 5%). Clothed manikin using cotton socks as under layer is better to measure R_{ct0} for all measured samples to ensure more stabilization and steady conditions before measuring R_{ct} as shown in Fig. 3. The stabilization process continues till the device reads the standard ambient conditions (T: 20 ± 2 °C, RH: 50 ± 5%), after that measurement of R_{ct0}, then stabilization (waiting for 20 min) while wearing CB sample over socks. Finally R_{ct} values can be measured using the measured R_{ct0} as a reference value, see Fig. 4 and Eq. (1) [4].

$$R_{ct} = \frac{A.(T_s - T_a)}{H} - R_{ct0} \quad (1)$$

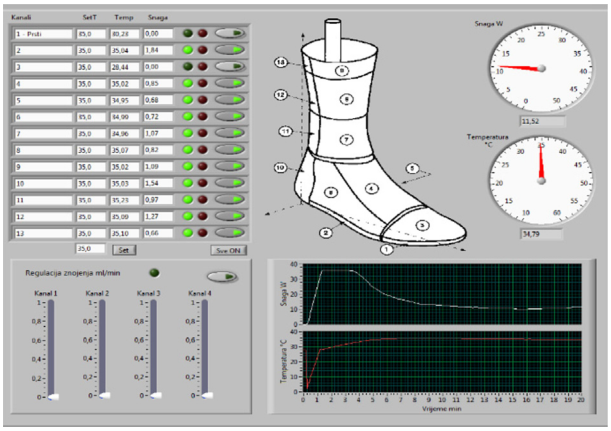
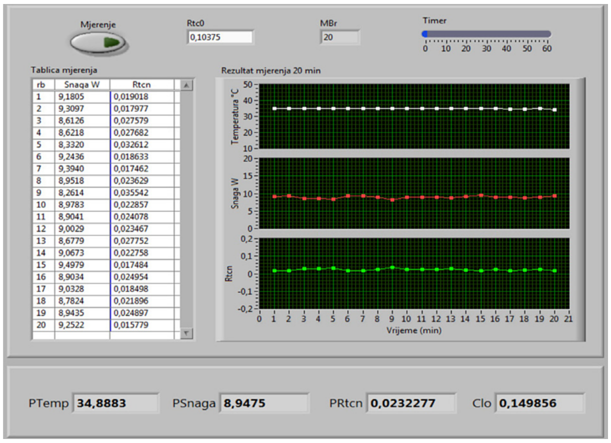


Fig. 3. Reaching steady state condition for all segments of TFM.

where: R_{ct}: dry resistance of sample only (m^2°C/W), T_s: hot plate surface temperature (°C), T_a: ambient temperature (°C), H/A: zone heat flux (W/m^2), R_{ct0}: clothed TFM dry resistance (m^2°C/W).



Rtc0 0,10375

MBr 20

Tablica mjerenja

rb	Snaga W	Rtcn
1	9,1805	0,019018
2	9,3097	0,017977
3	8,6126	0,027579
4	8,6218	0,027682
5	8,3320	0,032612
6	9,2436	0,018633
7	9,3940	0,017462
8	8,9518	0,023629
9	8,2614	0,035542
10	8,9783	0,022857
11	8,9041	0,024078
12	9,0029	0,023467
13	8,6779	0,027752
14	9,0673	0,022758
15	9,4979	0,017484
16	8,9034	0,024954
17	9,0328	0,018498
18	8,7824	0,021896
19	8,9435	0,024897
20	9,2522	0,015779

PTemp 34,8883

PSnaga 8,9475

PRtcn 0,0232277

Clo 0,149856

Fig. 4. Measuring R_{ct} while wearing CB over socks.

3. Results and discussions

3.1. Effect of room temperature and relative humidity on initial thermal resistance (R_{ct0})

Testing of R_{ct0} was performed on the same reference mercerized socks at three different conditions as follows: (T: 20 ± 2 °C, RH 65 ± 5%), (T: 22 ± 2 °C, RH 65 ± 5%), (T: 20 ± 2 °C, RH 50 ± 5%). The average values of R_{ct0} were 0.1152, 0.1117, and 0.1078 respectively, see Fig. 5. These results ensure that R_{ct0} is proportionally increases with the temperature difference ($\Delta T = T_s - T_a$), where T_s is skin temperature and T_a is room temperature. Moreover R_{ct0} values are increasing with higher relative humidity values which may achieve more insulation during winter season.

3.2. Effect of bandage extension and Rct0 on corresponding Rct values

As there are many factors can affect the thermal resistance measurements; it was necessary to measure R_{ct0} before each measurement of R_{ct} then calculate the relative change in thermal resistance (R_{ct}/R_{ct0}) to give accurate comparison between different bandage samples as shown in Figs. 6 and 7 for two and three layers bandaging. The effect of yarns material is summarized as well; the Cotton bandage has the lowest R_{ct} then VI-PA then VI-LY then CO-PA-PU due to the higher moisture regain of Cotton and Viscose compared to Polyamide and Polyurethane (8.5, 12, 4.5, and 0.3 respectively) [14,15]. Taking into consideration the fabric weight per unit area of VI-PA bandage that is 83.34 g/m^2 whereas CO-PA-PU is 236.48 g/m^2, which is another factor to limit and decrease the influence of Polyamide material while testing R_{ct}. These two Figs. 6 and 7 illustrates as well the combined effect of increasing the applied tension (at higher extension levels) on the contrary decreasing the total bandage thickness which generally decreases the R_{ct} values when increasing the bangae tension for both two and three layers.

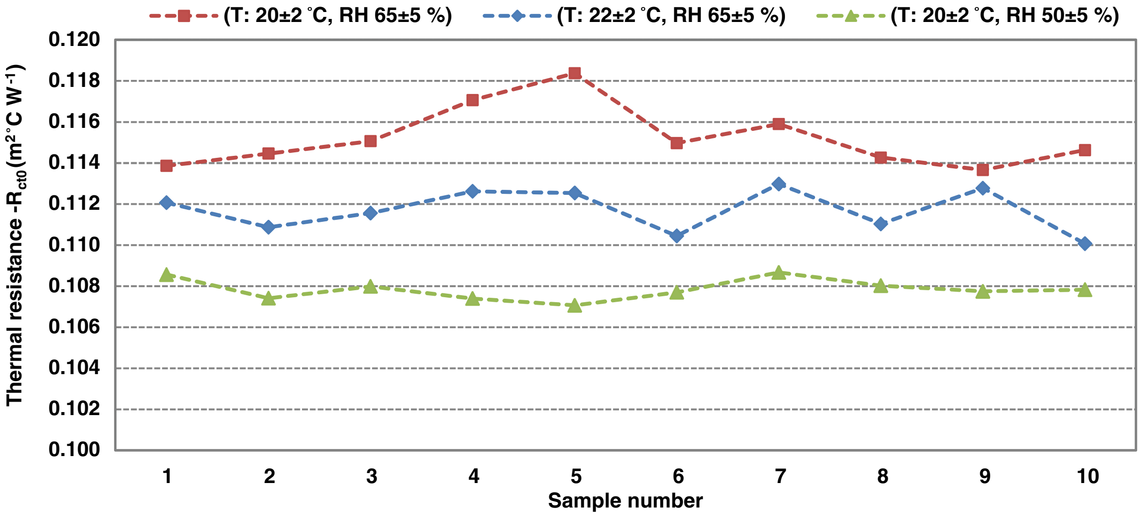


Fig. 5. Effect of room temperature and relative humidity on $R_{ct0.}$

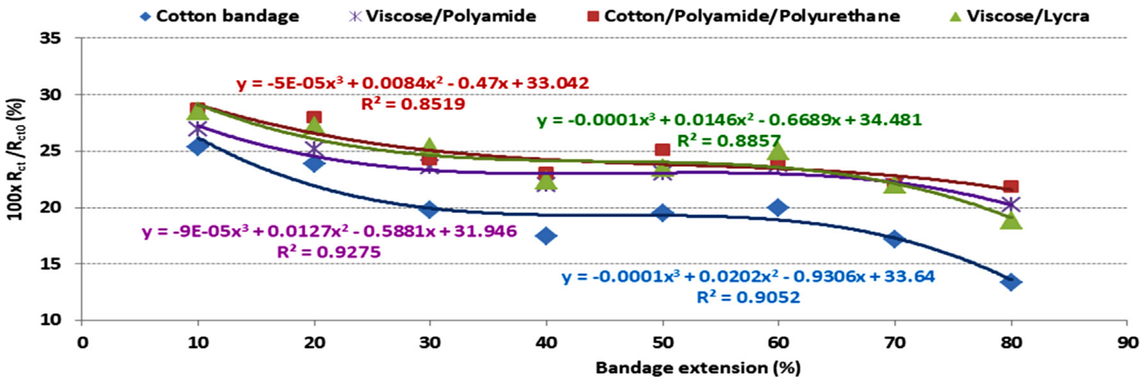


Fig. 6. Effect of extension on relative thermal resistance of two layers CB.

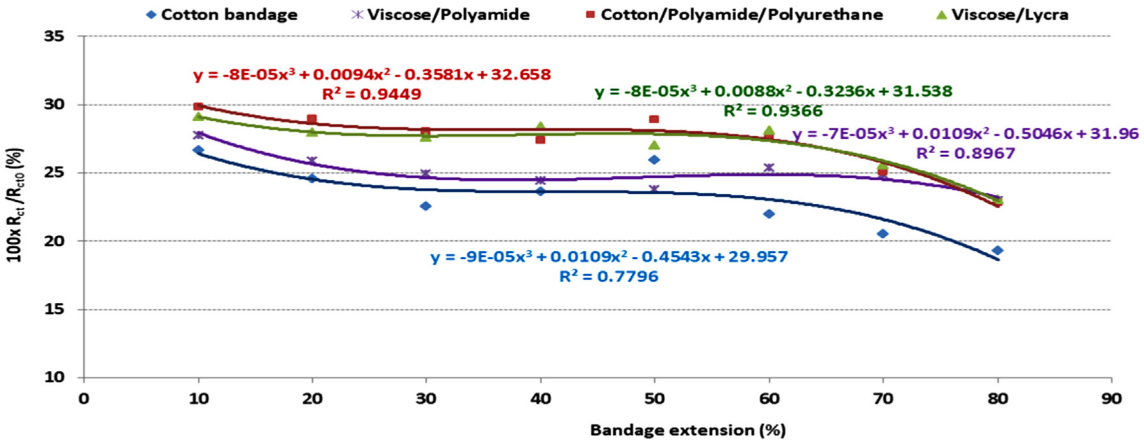


Fig. 7. Effect of extension on relative thermal resistance of three layers CB.

4. Conclusions

As a conclusion of this work, thermal resistance of clothed manikin is significantly decreases by increasing bandage extension from 10 to 40% then it is increases from 40 to 60% extension that may be due to the higher porosity of bandages (i.e. 0.364, 0.306, 0.471, and 0.325 for cotton, CO-PA-PU, VI-PA, and VI-LY bandages respectively) and optimum bandage thickness.

Acknowledgements

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