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Research paper

Thermophysiological Comfort Properties of Ripstop Fabrics for Enforcement Personnel Clothing

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Abstract

The choice of fabric parameters such as fiber type and structure play a key role in the thermoregulatory process as they can determine the change and loss of heat and moisture through sweat evaporation and heat dissipation. In this paper, the thermophysiological comfort properties of ripstop fabrics with different material composition percentages of polyester/cotton (P50C50 and P35C65) and nylon/cotton (N50C50 and N20C80) are reported. The study focuses on the fabric's air permeability, thermal resistance and water vapour resistance. The results suggest that the air permeability of the fabrics depends on thread density. Fabrics with the lowest thread density (P50C50) have a more open structure and therefore allow more air to pass through it. The results also indicate that the fibre content affects the thermal resistance of the fabrics. Fabrics with lower proportion of cotton, P50C50 and N50C50, show lower thermal resistance results. With regards to water vapour resistance, fabrics containing nylon fibres (N20C80 and N50C50) gave higher resistance in comparisons with fabrics containing polyester (P35C65 and P50C50). The opposite trend was seen with water vapour permeability results. Overall, fabric of P50C50 gave the best thermophysiological comfort properties as indicated from the study.

Keywords: *Air permeability; Ripstop; Thermophysiological Comfort; Water Vapour Permeability; Water Vapour Resistance*

1. Introduction

Enforcement personnel are usually equipped with different types of clothing such as parade suits, combat uniforms or operational uniforms, protective clothing for flying wear, high altitude dresses with extreme cold temperatures and security protection against nuclear, biological and chemical weapons [1]. The enforcement personnel safety and performance will depend heavily on the comfort of clothing that is worn [2]. Operational clothing, for example, should assist the personnel to act swiftly and efficiently while on duty without compromising comfort. Many studies have been conducted focusing on thermal stress in order to evaluate the thermal comfort of clothing as it is the main factor to the deterioration of human performance [3]–[6]. Recently, the focus has shifted to a less-learned area of tactical comfort [7].

During physical activities, heat pressure will be produced by the environmental factors together with active muscle, which leads to the core temperature and the skin temperature increases [8]. This situation can affect exercise performance. Therefore, when physical activity is carried out in a warm environment, the clothing with good dissipation will be of great advantage. This is because water transfer property of the clothing material, instead of the water absorption property, assist to dissipate sweat faster and avoids the rise of humidity and temperature at the skin surface, thus regulating a comfort microclimate clothing [9].

Clothing demonstrates a crucial function in the thermoregulatory process as it modifies the loss of heat and changes the loss of moisture from the human skin through sweat evaporation and heat dissipation [10]. Thus, the heat dissipation qualities of clothing worn by enforcement personnel at moderate or high workloads are important. Body temperature increases during exercise because muscular work and the metabolic processes linked with the activity to produce the heat energy. Humans can merely undergo a fluctuation in a body temperature of around 4°C. According to Behera *et al.* [11], the clothing thermal regulatory which the human body needs are approximately one (1) *clo* of the thermal insulation to withstand a temperature fluctuation of 4°C for both sides of the fabric, when the moisture transfer occurs through the textile material. Therefore, after any physical activity, the generated heat must move out from the body or hyperthermia can occur, which can hinder performance by affecting muscle function and metabolism, leading to premature fatigue [12]. Dissipation of heat could occur from convection or radiation of heat from the human skin to the environment, but heat is dissipated mainly by evaporation of perspiration from the skin.

Zhang *et al.* [13] studied the thermoregulatory reaction of physical activity in a controlled environment by studying the effect of the moisture transfer of clothing materials through the use of unskilled women. The designed physical activity is an activity that can cause distortion, where, water vapour and liquid water will be transferred simultaneously through the fabrics. It is inversely proportional to the rate of moisture transfer and the levels of relative humidity in the clothing microclimate. The higher humidity of the clothing microclimate will reduce the evaporation of sweat to the environment. The decreasing rate of the evaporation would cause the rectal temperature higher and consequence of this, the skin temperatures also will be increased. Thus, this phenomenon has shown that the rate of moisture transfer be as a major role in the thermoregulation reaction during physical activity.

In another study, Brazaitis *et al*. [14] examined the physiological and psychological reactions of several human subjects through intensive physical activity in a warm and humid environment. The eight selected subjects wore different type of fabric shirts made of polyester and cotton. It was found that doing exercise wearing polyester fabric gave low clothing regain but greater sweating efficiency compared to cotton fabric. Nevertheless, both fabrics gave identical thermophysiological comfort and subjective sensations. However, after the physical activity, subjects wearing the t-shirt made from polyester material felt faster skin temperature going back to the initial level but at slower thermal and rate of sweating sensation.

Many other studies have been conducted to study the thermophysiological comfort on commercial fabrics or clothes but research carried out on military uniforms are scarce, particularly in Malaysia. Most of the research conducted on military clothing are from the US Army Natick, an active agency that conducts research in military clothing in Massachusets, USA. This field of research is essential for hot and humid tropical weather as enforcement personnel are constantly exposed to heat hazards which may affect their performances. Enforcement personnel also wears the uniforms for routine tasks in offices, warehouses, maintenance facilities, and other Homeland Defense situations [15]. Because of its widespread use, it is important to understand the factors that contribute to the comfort aspects while wearing their uniforms.

2. Materials and methods

2.1. Materials

Four types of Ripstop fabric materials, mainly used by enforcement personnel, were selected (Table 1). All fabrics were obtained from commercial sources and measured for physical characteristics.

Table 1: Fabric Parameters

Fabric Material	Sample Code	Mass per unit area (g/m^2)	Thick-ness (mm)	Thread Count per cm		Ratio thread count warp & weft
				Warp	Weft	
20/80 Nylon/ Cotton	N20C80	232	0.47	43	27	0.628
50/50 Nylon/ Cotton	N50C50	234	0.49	40	21	0.525
35/65 Polyester/ Cotton	P35C65	234	0.48	48	23	0.479
50/50 Polyester/ Cotton	P50C50	232	0.48	39	17	0.436

2.1 Methods

i. Air permeability

The air permeability measurements of samples were performed according to ISO 9237 standard using SDL M021 Air Permeability Tester at 200 Pa and with sample cross-sectional area of 20 cm^2. Test results were expressed as air permeability in L/m²/s at a specified pressure. Five specimens from every fabric sample were evaluated for air permeability.

ii. Thermal resistance (Rct)

The simulation of heat and mass transfer processes that occur next to the skin surface was conducted using Sweating Guarded Hotplate Model M259B which it is often referred as skin model.

The environment condition requires a relative humidity range of 65 ± 3% non-condensing and the temperature range of 20 ± 1^{o}C. Samples of 500 x 500 mm in dimensions were cut diagonally and conditioned for 24 hours according to ISO 139:2005. The test equipment consists of a guarded hot plate assembly together in a climatic chamber. The air speed was set to 1 ± 0.05 m/s and the temperature of the guarded hot plate was maintained at 35° C (temperature of human skin) and standard atmospheric conditions of 65% RH and 20° C temperature were maintained [16], [17]. Data from three replicate measurements were averaged to determine the mean value for each fabric. The total thermal resistance of the fabric was calculated using Equation 1:

$$Rct = \left(\frac{(Tp - Ta).A}{Hc}\right) - Rct0 \qquad (1)$$

where,
Rct is the thermal resistance (m^{2}K/W)
Rct0 is the thermal resistance without a sample (m2K/W)
Hc is the heating power (W/m^2) supplied to the plate to maintain a temperature of 35°C
Tp is the plate temperature (° C) in the test enclosure (35° C)
Ta is the air temperature (° C) in the test enclosure (20° C); and
A is the area of the test section (m^2).

iii. Water Vapour Resistance (Ret)

The Water Vapour Resistance (Ret) was also tested using the Sweated Guarded Hotplate. The instrument simulates the moisture transport through textiles when worn next to the skin. It measures the 'latent' evaporative heat flux across a given area in response to a steady applied water vapour pressure gradient, as described in ISO 11092:2014. The air temperature was set to 35° C and the relative humidity at 40% and the air speed generated by the airflow hood was 1 ± 0.05 m/s. The total vapour resistance of the fabric was measured and calculated after the system reached a steady state. The water vapour resistance (Ret) was calculated using Equation 2:

$$Ret = \left(\frac{(Pp - Pa).A}{He}\right) - Ret0 \qquad (2)$$

where,
Ret is the water vapour resistance (m^2. Pa/W); Pp is the water vapour pressure (Pa) at the plate surface; Pa is the water vapour pressure (Pa) of the air; He is the heating power for measuring water vapour resistance (W/m^2) by the instrument; and Ret0 is the evaporative resistance measured for the air layer.

iv. Water Vapour Permeability

Characteristic of a textile material or composite depending on water-vapour resistance and temperature in accordance with Equation 3:

$$Wd = \frac{1}{Ret.\varnothing Tm} \qquad (3)$$

Where,
ϕTm is the latent heat of vaporization of water at the temperature Tm of the measuring unit, equals 0.672 W.h/g at Tm = 35 ^{o}C. Water vapour permeability is expressed in g/m^{2}hPa.

3. Results and discussion

3.1. Air permeability

As shown in Fig. 1, the results indicate that the P50C50 fabric has the highest value of air permeability followed by the N50C50 and P35C65 fabrics. The lowest value of air permeability is the N20C80 fabric. As indicated in Table 1 above, all the samples have almost the same fabric density, which is fabric weight and fabric thickness about 232 g/m^2 and 0.47 mm respectively. The difference is only on the ratio of thread count for warp/weft and the fiber density. According to Amran *et al.* [18], air permeability is not dependent to the fiber type. The factor that partly contribute to air permeability is higher thread count warp/weft, fabric thickness and fabric density. The thread count per cm on the warp direction is 39 and on the weft direction is only 17. Thus, it will allow more amount of air to penetrate the fabric due to the looseness of the fabric structure. On the other hand, this suggests that P50C50 has a larger pore size than other fabric. This result is supported by a study conducted by Guocheng Zhu *et al.* [19] where fabrics with the larger pore size and greater pore ratio to the total area of the fabric have higher air permeability. The fabric's surface structures were observed using Olympus SZX16 Stereo microscope as shown in Fig. 2. The P50C50 fabric has larger pore size with many even surface. The N50C50 and P35C65 fabrics have smaller pore while the N20C80 fabric has the smallest pore size as the light could not penetrate the fabric pores.

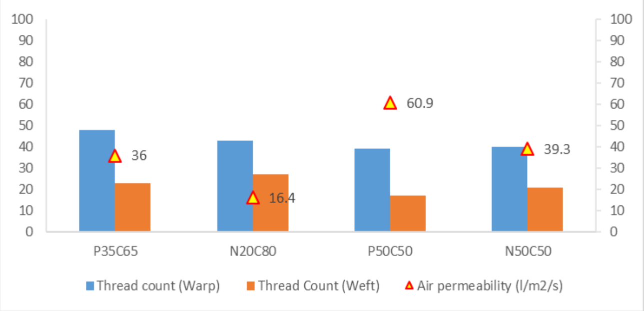

Fig. 1: Air permeability value versus thread count (warp & weft)

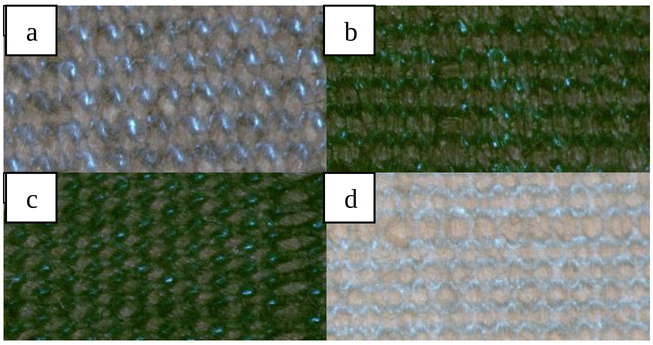

Fig 2: Differences in fabric pores, a. Sample P50C50, b. Sample N50C50, c. Sample P35C65 and d. Sample N20C80, 10X.

3.1. Thermal Resistance

The results of thermal resistance of the individual value are shown in Fig. 3. The P35C65 fabric has the highest thermal resistance value (0.0341 m^2.K/W) among the fabrics tested and followed by N20C80. This result corresponds to Tausif *et al.* [20], which states that the thermal resistance is greatly influenced by the fiber type besides yarn properties, fabric structure, finishing treatments and clothing conditions. Both samples have higher content of cotton fibers at 65% and 80%, respectively.

Fig. 4 shows that the air permeability is inversely proportional to thermal resistance. Fabrics with high air permeability readings will have lower readings in thermal resistance. This corresponds to the study conducted by Zhu *et al.* [19] stating that the thermal resistance decreases with increased air permeability. This is because the value of air permeability is strongly influenced by the size of the fabrics pore compared to porosity. However, thermal resistance is significantly influenced by the fibre type, yarn properties and fabric structure.

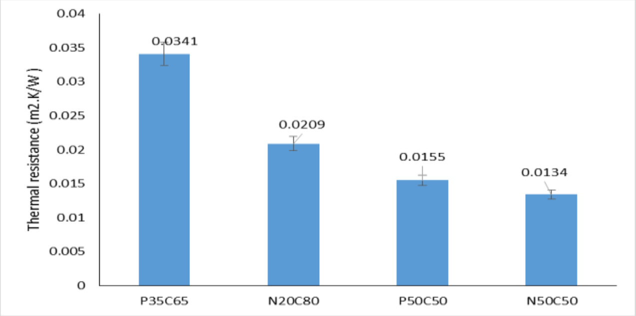

Fig. 3: Thermal resistance of blended fabric samples

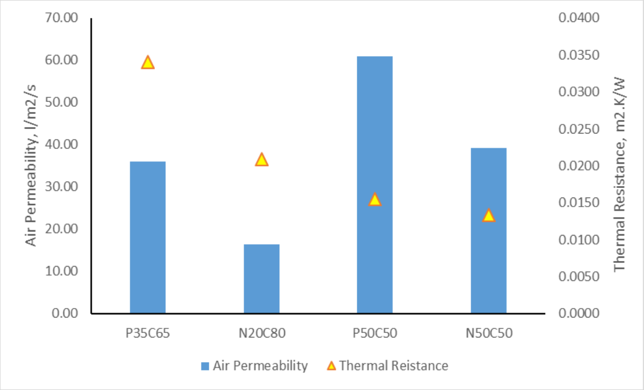

Fig. 4: Air permeability versus thermal resistance

3.2. Water Vapour Resistance

The water vapour resistance of a material is a measure of the material's reluctance to let water vapour pass through. If the water vapour resistance of a clothing fabric is high, it prevents evaporative cooling of the skin. Thus, produced and stored heat that cannot be dissipated from the body may lead to uncomfortable condition for a wearer. The results of the water vapour resistance from the plot of the individual value are shown in Fig. 5. It can be seen that the highest value of water vapour resistance is the N20C80 fabric with 4.40 m^2.Pa/W. This result is followed by the N50C50 and P35C65 fabrics with readings of 3.74 m^2.Pa/W and 2.97 m^2.Pa/W respectively. The lowest value of water vapour resistance is the P50C50 fabric. This means that this fabric does not entrap air inside the clothing and the wearer feels more comfortable as the fabric allows the air to pass through the fabric pores. Furthermore, this fabric is able to transmit air and water vapour much better to the other side of the fabric in comparison with other fabrics samples.

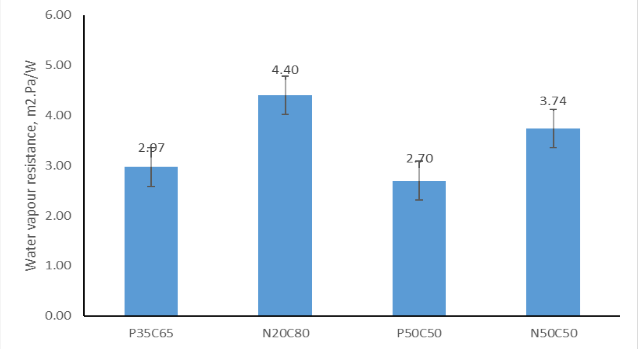

Fig. 5: Water vapour resistance for each sample

Fig. 6 shows the individual value of water vapour permeability of fabric samples compared to air permeability. It can be seen that the P50C50 fabric has better water vapour permeability and also air permeability results. This means that the fabric is able transport air and water vapour much better to the other side of the fabric compared to other fabric samples.

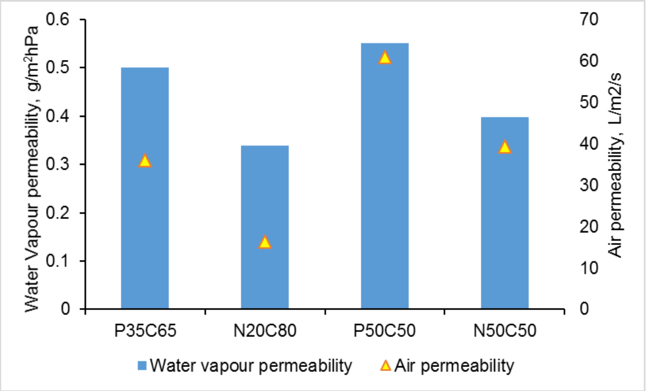

Fig. 6: Water vapour permeability of blended fabric samples versus air permeability

4. Conclusion

This study focuses on the factors that will affect the properties of thermal resistance, water vapour resistance and air permeability. The thermal comfort of the fabrics is characterized in terms of thermal resistance, water vapour resistance, air permeability and fabric porosity. The results show that to improve the thermal resistance of the fabric during wear, selection of raw materials is the most important factor rather than other physical properties although it can still affect thermal resistance such as the size of the fabric pore. However, to improve the water vapour resistance and air permeability, the physical properties of the fabric such as threads count, structure, fabric mass and thickness must be considered. On the other hand, although cotton fibers have a high correlation to moisture, the raw material effect on water vapour resistance of the fabric depends on the other factors such as thread count and the type of fiber the cotton fibers are blended with.

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