A PROPOSAL FOR DESIGNING KNITTED FABRIC FOR THE“WEAR PROMOTES EXERCISE EFFECT” WITH THE PURPOSE OF IMPROVING COMFORT

Yoshitaka Niimi[1,2], Antonín Havelka[1] and Hiroyuki Kanai[2]

[1]*Department of Clothing Technology, Faculty of Textile Engineering, Technical University of Liberec, Studentská 2, 461 17 Liberec, Czech Republic*
[2]*Department of Advanced Textile and Kansei Engineering, Faculty of Textile Engineering, Shinshu University, 3-15-1 Tokida, Ueda City, 386 8567 Nagano, Japan*
k.m.fro.ymg@gmail.com, antonin.havelka@tul.cz, kanai@shinshu-u.ac.jp

Abstract: *In this paper a study on Compression IW (Inner Wear), the base fabric of TIW (Training Inner Wear), which promotes the exercise effect while walking, will be described. Although the function of clothing is to make and keep a comfortable environment with thermal, compression and tactile comfort, the comfort of TIW has so far not been considered. The main purpose of this research is to recommend TIW, which can be used to make comfortable clothing and maintain the exercise effect in casual wear. Proposed samples of base fabric for TIW were designed by focusing on “material / fineness / density / PU mixing ratio” to improve comfort and maintain function. The thermal properties that are important for clothing comfort were evaluated; especially thermal resistance and water vapor permeability, and tensile properties that are related to fabric stiffness and hoop tension were also measured, because TIW works on the principle of suppressing clothing deformation. These results will be reference values for designing TIW's base fabric.*

Keywords: *Functional clothing, Compression inner wear, Thermal comfort, Tensile property.*

1 INTRODUCTION

The number of obese Japanese people in the 20s to 70s age range is increasing nowadays and one of the reasons for this problem is a lack of exercise [1]. According to the National Health and Nutrition Survey (2014) by the Ministry of Health, Labor and Welfare, approximately one out of two people in Japan do not spend any time at all exercising; the percentage of these people in their 20s to 40s is especially high [2]. Therefore, they recommend walking 9000 steps (energy consumption: 270 kcal) per day to prevent increasing obesity; however, the average number of walking steps per day (for people in their 20s to 40s) is currently approximately 7400 (energy consumption: 220 kcal). The main reasons why they do not exercise are that they do not have time for it and they usually feel tired after work, both of which are related to the Japanese style of hard work that is forced by long-time labor [3]. Hence, it is efficient to design a product that can promote the exercise effect without spending time exercising in a business situation such as commuting. In a previous research, Training Inner Wear (TIW) was proposed as the wear that promotes exercise effect to the wearer, and it is composed of Low stretch tapes and Compression Inner Wear (IW). The TIW changes wearer’s muscle activity during their walking motion [4]. However, TIW was designed to do this as its main purpose without considering comfort, which is one of the important functions of clothing [5]. Therefore, it is necessary to design and evaluate TIW considering not only its function but also comfort.

2 EXPERIMENTAL SAMPLES

2.1 TIW (Training Inner Wear)

TIW is composed of Low stretch tapes and Compression IW. The tapes have a function of restraining body motion, and the IW is the base fabric to which tapes are attached for TIW. It was already decided how the tapes should be applied to the IW in previous research, as can be seen in Figure1. Each tape has different functions for wearer body. TAPE.01 suppresses a flexion of the knee joint and an extension of the hip joint and TAPE.02/03 suppress a lateral rotation and an abduction of the hip joint. TAPE.04 suppresses an extension of the knee joint and a flexion of the hip joint and TAPE.05 suppress a medial rotation of the hip joint. These tapes have the role of suppressing clothing deformation, which was proposed as a method to obtain the TIW exercise effect; hence the positions in which the tapes were applied were selected according to the level of clothes deformation, which was measured by motion analysis in previous research.

It has been already reported that the exercise effect which means Energy Consumption caused by wearing TIW increased approximately 9% while walking [5].

Figure 1 The tapes which promote exercise effect of TIW

In addition, it was confirmed that the effect depends on the tapes by a result of an exhalation analysis. Therefore, we tried to improve the comfort of TIW by changing the fabric of the IW, which does not relate to the exercise effect and which also contacts the skin directly.

2.2 Proposed sample (base fabric for TIW)

In this research, a new base fabric (IW) is proposed to improve TIW comfort. Polyester, which is normally used as sportswear material, has been used as the base fabric material for TIW until now; however, it causes discomfort from dampness between the skin and the clothing layer because polyester has low moisture content and does not absorb water. As a new base fabric, samples of cotton material were proposed; this is widely used for underwear due to good water absorbency and softness to the touch. Cotton is not generally used in clothing for exercise because cotton does not have quick-drying properties [6]. However, TIW is used in daily situations which do not produce much sweat, which is why cotton was selected as the new base fabric of TIW. Furthermore, it is generally better to constitute TIW base fabric with warp (tricot) knitted fabric, which is widely used as sports innerwear because tricot has excellent elasticity and is comfortable and better fitting [7]. However, natural materials such as cotton are not suitable for warp knitted fabric because it is easy for natural material yarns to break due to the high load that is necessary for warp knitting. Therefore, plain knitted fabric was selected as the TIW base fabric.

However, it easily stretches with this structure, so that, to maintain the TIW's function even after changing the base fabric, we focused on those parameters (fineness / density / PU mixing ratio) that affect fabric rigidity and hoop tension, because the TIW functions by suppressing deformation of clothing. Regarding between IW(C1) and IW(C2), their fineness is different as you can see Table 1; IW(C1)'s is thicker. And, between IW(C2), IW(C3) and IW(C4), their density is different by treating a fulling finish.

These sample's information is given in Table 1 below. Additionally, this IW is made so that course direction is in the circumference direction, while wale direction is in the height direction, as you can see in Figure 2.

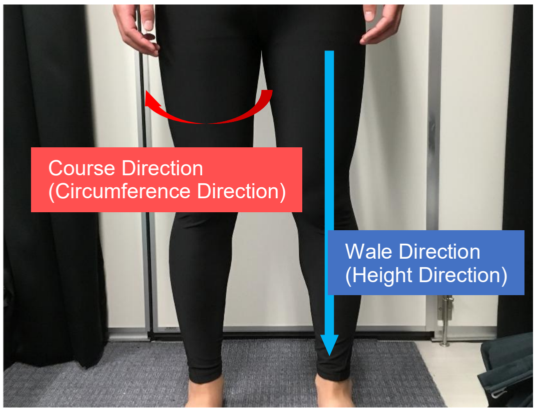


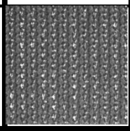
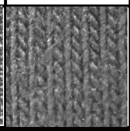
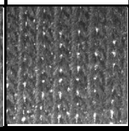
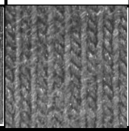
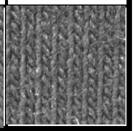
Figure 2 How to knit IW (each direction)

3 METHODS

In proposing a new TIW base fabric (IW), the focus is on two aspects. The first is (1) Maintaining the function of TIW, the second is (2) Improving the comfort of TIW.

Regarding (1), it is necessary to take into account shape stability and displacement by cloth-stretching during the walking motion. The results of motion analysis of TIW show how much deformation each part of IW undergoes, and the tapes attached to the IW must all hold the correct position. It means that it is necessary to confirm the tensile workload and tensile recovery of the IW. Therefore, tensile properties were measured for comparison between each sample.

Table 1 Details of the fabric samples

Sample Name		IW(P)	IW(C1)	IW(C2)	IW(C3)	IW(C4)
						
blend ratio [%]	PET	70	0	0	0	0
	Cotton	0	92	95	88	88
	PU	30	8	5	12	12
weight [g/m²]		263.2	224.5	158.2	189.1	214.9
thickness [mm]		0.78	1.03	0.92	0.98	1.00
yarn density	[wales/2.54cm]	66.0	54.0	57.0	62.0	64.0
	[courses/2.54cm]	66.0	38.0	40.0	42.0	45.0
density		66.0	46.0	48.5	52.0	54.5
apparent fineness [tex]		-	21.4	14.5	14.4	15.0
Total volume of pore space [mm³]		0.0631	0.0980	0.336	0.105	0.109
knit construction		Tricot	Plain Stich	Plain Stich	Plain Stich	Plain Stich

Regarding (2), the clothing comfort is composed of three factors which are thermal property, compression property and touch feeling property [8]. In this paper, thermal comfort is discussed as the primary one, as an important function of clothing is to provide aid in maintaining the thermal balance of the human body and ensure that the heat loss, skin temperature, air movement and humidity at the body surface produce a sensation of comfort [9]. Thermal comfort has a relationship with the "clothing climate", which is the climate environment between the human skin and the clothing; this means that Heat transfer, Moisture transfer and Air transfer are important factors [10]. Therefore, the physical properties were measured to confirm the differences in character between samples.

3.1 Tensile property

Tensile property was measured to compare the tensile workload and tensile recovery for each sample, and it was examined by a tensile test with a Tensile and compress testing machine (STA-1225: ORIENTEC) according to Method D (repeated constant elongation method) and Method E (repeated constant load method), which is described in JIS L 1096.

The state where the sample (50×300 mm) was stretched by a constant load was held for a minute, and then it was held again for 3 minutes in a state where it had recovered the position that it had with the initial load. After that process, the grasping interval of the sample was measured under the initial load. Measurement conditions were: Initial load: 29 mN; Grasping interval 200 mm; Grasping width 50 mm; Maximum load 7.25 N; Tensile speed 20 mm/min and the experimental conditions were 23±2°C / 50±4%R.H.

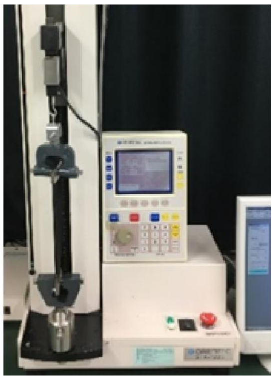


Figure 3 Tensile testing machine (STA-1225: ORIENTEC)

From the Stress [F] - strain [ε] curve (Figure 4) made by the tensile test result, the following values for each feature were calculated.

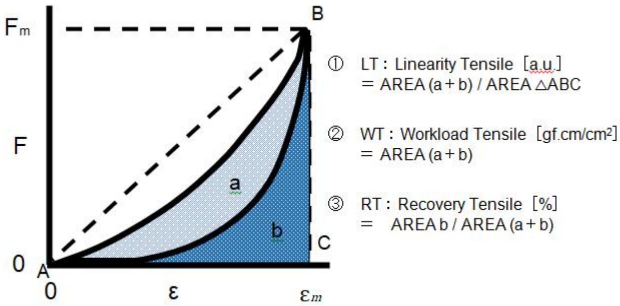


Figure 4 Each feature values from tensile test

3.2 *Thermal property*

As I mentioned, thermal comfort has a relationship with the Clothing Climate environment between the human skin and the clothing, and thermal comfort means that Heat transfer, Moisture transfer and Air transfer are important factors. Especially, Heat transfer and Moisture transfer are important factor for discussing thermal comfort [11]. In addition, air permeability is also important factor, however in the case of having space between skin and clothing [12]. That is why we focus on Heat transfer and Moisture transfer. The method for measuring each physiological property is described below.

Figure 5 Special type thermal characteristic measuring device (NT-H1: KATOTECH)

Heat transfer

Heat transfer was measured with special type thermal characteristic measuring device (NT-H1: KATOTECH). It can evaluate Thermal resistance, Thermal conductivity and Q-max. Experimental conditions were 23±2°C and 50±4% R.H. The values could be calculated by the following methods and equations:

$$R_{ct} = (a - b/a) \times 100 \qquad (1)$$

where: R_{ct} - Thermal resistance [%], a - Heat flow (no sample) [W], b - Heat flow (each sample) [W].

$$\lambda = (d \times Q)/(A \times \Delta T) \qquad (2)$$

where: λ - Thermal conductivity [W/(m.°C)], d - Thickness [m], Q - Heat flow [W], A - Contact area [m^2], T - Temperature [°C]

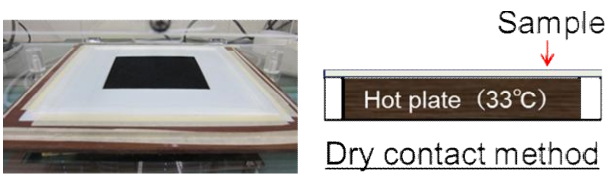


Figure 6 Special type thermal characteristic measuring device (NT-H1: KATOTECH): Thermal resistance

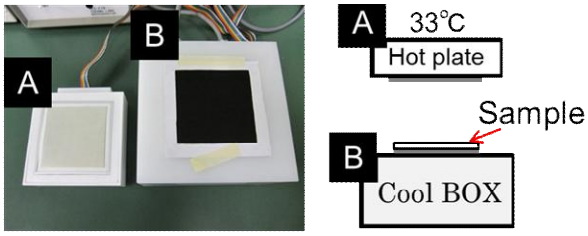


Figure 7 Special type thermal characteristic measuring device (NT-H1: KATOTECH): Thermal conductivity

Moisture transfer

The Sweating Guarded Hotplate (SGHP: Thermetrics) was used, often referred to as the Skin Model, to measure water vapor resistance of samples in accordance with ISO 11092. The temperature of the test plate, guard section and bottom plate were maintained at 35±0.5°C without fluctuating more than ±0.1°C during a test. The air temperature was the same as the plate temperature. The relative humidity was 40±4% R.H. and air velocity was maintained at 1.0±0.1 m/s.

$$R_{et} = (P_s - P_a)A / H_E \qquad (3)$$

where: R_{et} - Water vapor resistance [kPa.m^2/W], P_s - Water vapor pressure at the plate surface [kPa], P_a - The water vapor pressure in the air [kPa], A - Area of the plate test section [m^2], H_E - Power input [W].

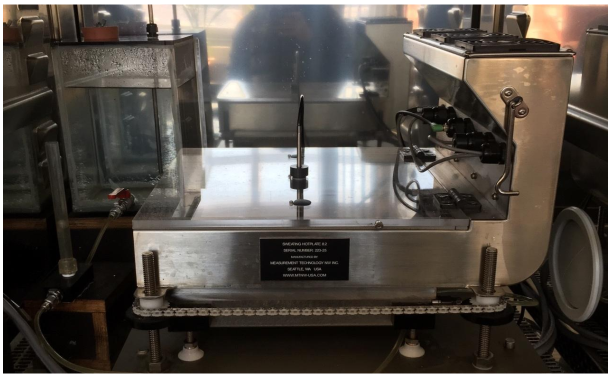


Figure 8 Sweating Guarded Hotplate

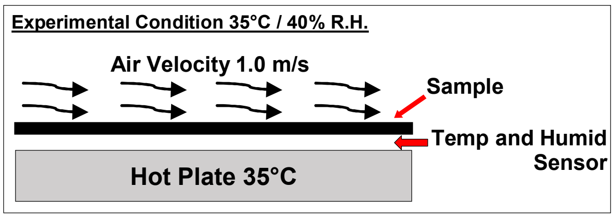


Figure 9 Sweating Guarded Hotplate

4 RESULTS AND DISCUSSION

4.1 *Tensile property*

The analyzed data (WT: Workload Tensile and RT: Recovery Tensile, LT: Linearity Tensile) which were calculated from Stress-strain Curve are shown on

Table 2. Then, it will be described about each result (WT and RT).

Table 2 Physical properties of each sample

Sample		*IW(P)*	*IW(C1)*	*IW(C2)*	*IW(C3)*	*IW(C4)*
Density		66.0	46.0	48.5	52.0	54.5
Fineness [tex]		-	21.4	14.5	14.4	15.0
Linearity Tensile [a.u.]	Wale	1.03	0.789	0.659	0.773	0.786
	Course	0.958	0.875	0.758	0.836	0.907
Recovery Tensile [%]	Wale	73.6	36.6	26.7	37.9	40.2
	Course	61.3	37.2	26.6	36.3	39.0
Workload Tensile [gf.cm/cm^2]	Wale	54.4	36.8	36.6	37.1	42.7
	Course	50.8	54.9	68.5	55.4	69.8

WT (Workload Tensile)

It can be recognized from the result whether how much easy to stretch the fabrics and can be seen that there is a different tendency between IW(P) and IW(C) from Figure 10, what IW(C) is lower than IW(P) that is why it describes that fabric of IW(P) is easier to stretch than IW(C), regarding WT of wale direction (Height direction against the body). On the other hand, regarding course direction (Circumstance direction against the body), IW(C) is higher than IW(P) that is why it describes that it is an opposite tendency with wale direction.

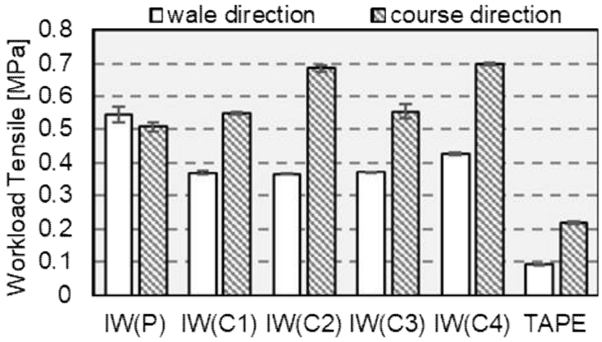


Figure 10 WT (Workload Tensile)

About the human skin deformation during walking, the deformation of a knee that is the main part of a big movement during walking and it is different between wale direction and course direction. It is mentioned that elongation of skin on wale direction has more than course direction about 1.6 times [13]. If it will be mentioned about IW(C), the fabric is not easier to stretch to the height direction (wale direction) that the skin's deformation is high during walking, it might make uncomfortable to the wearer. On the other hand, the fabric is easier to stretch to the circumstance direction (course direction) that is related to hoop tension which effects to a shape stability of clothing, it might make a decreasing clothing stability has related to hoop tension.

RT (Recovery Tensile)

RT of IW(P) and IW(C) is totally different because IW(P) is a warp knitting and be inserted much more PU than IW(C). According to previous research, six IW samples, that are tricot knitted fabric on the general market, are measured their RT by the same method and condition with this experiment, and it is reported that RT average of course direction and wale direction are 57% [5]. Therefore, it can be recognized that it is not enough RT of IW(C) as you can see in Figure 11. The exercise effect of TIW will be not applied if it has not enough RT for IW, because it makes lack of clothing stability. That is why it is necessary to have a sufficient RT for applying to a practical product. It can also be mentioned from the fact that there is a significant correlation between RT and PU mixing ration as you can see Figure 12. It means that the RT will increase if the samples have much PU mixing ration.

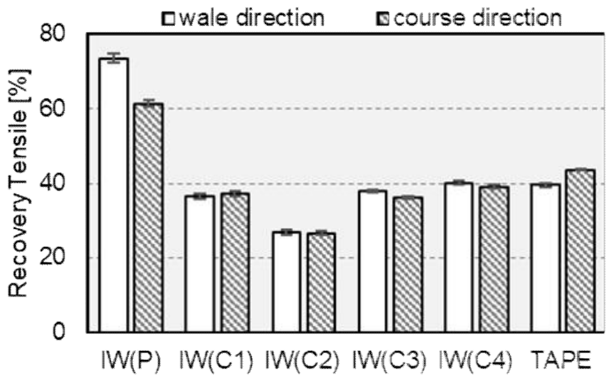


Figure 11 RT (Recovery Tensile)

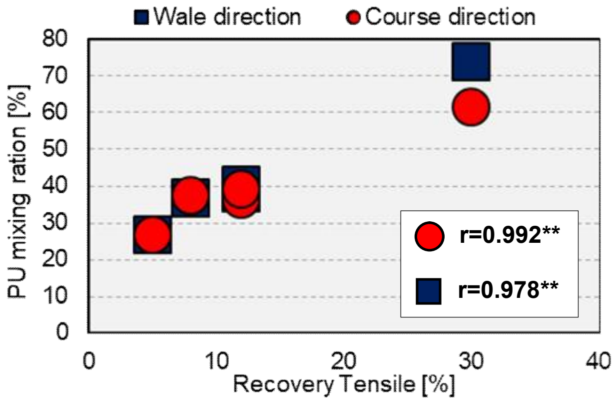


Figure 12 Correlation between RT and PU mixing ratio

4.2 Thermal property

The results, which are shown as Table 3, describe each thermal property that was measured. Measuring of both thermal resistance of clothing and the ability of a fabric to transport the water vapor emitted from the body are important factors in assessing the thermal comfort [11]. Therefore, it is shown the results of important factors below with figure.

Table 3 Thermal physical property of each sample

Sample	*IW(P)*	*IW(C1)*	*IW(C2)*	*IW(C3)*	*IW(C4)*
Thermal Resistance [%]	24.7	29.3	39.7	34.9	34.7
Thermal Conductivity [W/(m.°C)]	0.0591	0.0631	0.0580	0.0604	0.0616
Q-max [W/m^2]	0.0586	0.0502	0.0510	0.0504	0.0482
Air Resistance [kPa.S/m]	0.146	0.824	0.322	0.552	0.756
Water Vapor Resistance [m^2.Pa/W]	3.58	5.01	4.59	4.00	4.29

Table 4 Result of variance analysis

Multiple Comparison (Tukey)			Result				
			(P)	(C1)	(C2)	(C3)	(C4)
P Values	**Thermal Resistance**	**(P)**	-	*	**	**	**
		(C1)	0.01	-	**	**	**
		(C2)	0.00	0.00	-	**	**
		(C3)	0.00	0.00	0.01	-	
		(C4)	0.00	0.00	0.01	1.00	-
	Thermal Conductivity	**(P)**	-	**			*
		(C1)	0.00	-	**	*	
		(C2)	0.55	0.00	-	*	**
		(C3)	0.43	0.01	0.03	-	
		(C4)	0.03	0.28	0.00	0.54	-
	Thermal Conductance	**(P)**	-	**	**	**	**
		(C1)	0.00	-			
		(C2)	0.00	0.22	-		
		(C3)	0.00	0.99	0.44	-	
		(C4)	0.00	0.99	0.38	1.00	-

* 5% significant ** 1% significant

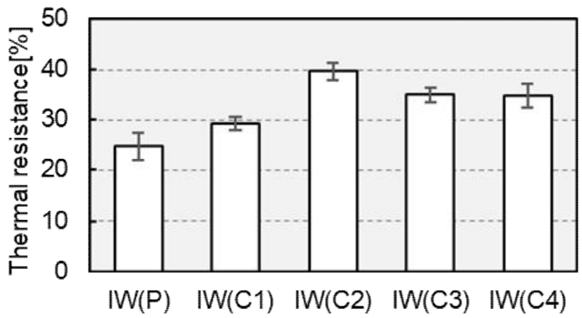


Figure 13 Thermal resistance

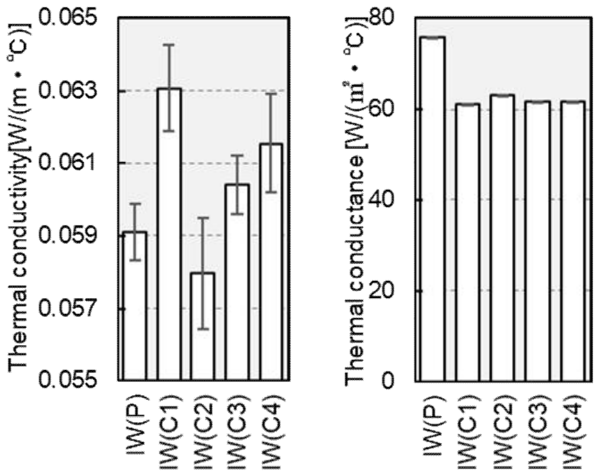


Figure 14 Thermal conductivity / conductance

Heat transfer

It can be recognized the heat transfer features of these samples from Figure 13, what IW(C)'s thermal resistance is significantly higher than IW(P), and each cotton samples have significant different except between IW(C3) and IW(C4). It means that Changing material/fineness, and also Applying fulling relate to thermal resistance. And also, we can say that the result should relates to Total volume of pore space from Table 1 and Figure 13. If a fabric contains much air which is related to thermal conductivity, thermal resistance should be higher under the condition without air flow.

Regarding thermal conductivity, we calculated thermal conductance with removing thickness factor. As you can see in Figure 14 (right), IW(P)'s thermal conductance is significantly higher than IW(C), and each IW(C) samples do not have significant different. On the other hand, as you can see in Figure 14 (left), each cotton sample has different tendency about thermal conductivity. From these results, it can be the thickness factor has the most influence on thermal conductivity.

Water vapor resistance

It is possible to see the result that have different values of Water Vapor Resistance between IW(P) and IW(C). IW(P)'s is lower than IW(C)'s. The reason of the result relates to sample's material; Polyester material feature is a low water content, on the other hand, cotton material has high water absorption. That is why, it is difficult for water to through the cotton fabric.

In addition, in the case of comparing between each IW(C) samples, it is found that the resulting values are larger in the order of IW(C1) > IW(C2) > IW(C4) > IW(C3); it could be guessed that it means the result relates to Cotton Mixing Ration and Density. Although there is a difference between each sample as described above, each sample has excellent in Water Vapor Permeability because it means high Water Vapor Permeability when the value is between 0.0 and 6.0 [14]. That is why these IW samples are suitable for based fabric for TIW in terms of Water Vapor Permeability.

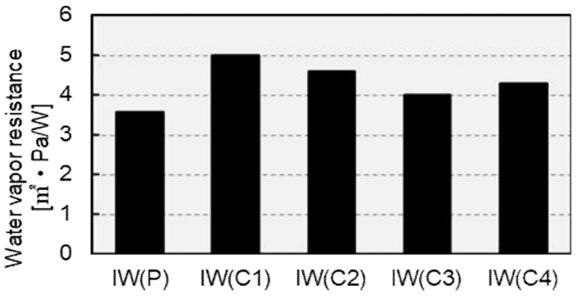


Figure 15 Water vapor resistance

4.3 Summary of the results

About Tensile property

The fabric IW(C) are easier to stretch to the circumference direction that is related to hoop tension which effects to a clothing shape stability, it might make a decreasing clothing stability has related to hoop tension. Furthermore, the fabric IW(P) is easier to stretch to the height direction that is related to mobility which effects to a clothing comfort. Therefore, exchanging the knitted direction should be a good way for applying TIW because the hoop tension and the comfort is going to be increased.

In addition, set RT 57% is a target value for a general tricot knitted, so that it is not enough RT for IW(C) from the result. It is necessary to design TIW again with considering their PU mixing ration.

About Thermal property

1. Compare IW(P) and IW(C)

Thermal properties which are Heat transfer and Water vapor permeability were changed by changing material. IW(C)'s Thermal conductivity is lower than IW(P), while Thermal resistance is higher. IW(C)'s Water vapor resistance is higher than IW(P); however, we could know that both material fabrics have an excellent Water vapor permeability from the reference.

2. Compare each IW(C)

Changing material/fineness, and also Applying fulling relate to thermal resistance. And also, the result should relate to Total volume of pore space. If a fabric contains much air which is related to thermal conductivity, thermal resistance should be higher under the condition without air flow.

Regarding thermal conductivity, most results of comparison between IW(C)'s are significantly different; however, their value of thermal conductance is almost same result. From the result, thickness factor should be the most influence factor on thermal conductivity.

The thickness that is changed by fulling and fineness is most related to heat transfer. In the case of thickness is large, thermal resistance is lower, and then thermal conductivity is higher.

5 CONCLUSION

In this paper we proposed a Compression IW (Inner Wear), the base fabric of TIW (Training Inner Wear) which promotes the exercise effect during walking to improve comfort while maintaining the function. The tensile property and thermal property are measured to confirm physical properties of samples that is changed Material / Fineness / Density / PU mixing ratio to achieve our purpose. From measurement results, we could figure out some positive points, and some negative points as I describe in this paper. Therefore, IW(C) will be re-proposed, and then we will measure the physical properties and to carry out a sensory test to evaluate the objective comfort as next step.

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