Investigation on the Concealing Effect of Polyester/Stainless Steel Blended Fabrics in Far Infrared Spectral Range

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Abstract: *In this research, an attempt is made to investigate the concealing behaviour of the fabrics produced with polyester and stainless steel conductive yarns in the far infrared (FIR) spectral range. Firstly the collected polyester and stainless steel conductive yarns are identified. Secondly warp and filling yarn preparation processes are done. Thirdly the five different types of camouflage fabrics are constructed on hand loom. Fourthly the preparation of equipment for thermal signature concealing test is made. Finally the thermal signatures and physical properties of the produced samples are investigated and discussed. It is observed that the best thermal signature concealing effect can be obtained by laying the two layers of sample fabrics in which the sample (P_5) constructed of 100 percent polyester yarns is used as inner layer and the sample (PS_2) constructed of polyester and stainless steel conductive yarns is used as outer layer.*

Keywords: *Polyester Yarn, Stainless Steel Conductive Yarn, Far Infrared Spectral Range, Camouflage Fabrics, Thermal Signature Concealing Effect*

1. INTRODUCTION:

Today, camouflage uniforms are worn by all soldiers in the military. Camouflage is an important part of the modern army. It is a tool that breaks up the soldier's recognizable human form. This blending into the environment enables the soldiers to spot the enemy first.

Thermal infrared camouflage fabrics are used for covering on human in order to reduce the thermal infrared (IR) signature of the human target in the open. Especially polyester fabrics are commonly used in military due to strong fibre with good resilience, thermal shaping and durability. But polyester fabrics have high emissivity that can be easily detected by thermal imagers. To overcome this technical problem, a shiny metallic surface such as stainless steel is used as the whole part of the fabric or the partial part incorporated in the polyester fabric due to the low emissivity of stainless steel. Therefore, the emissivity of the target can be reduced by using the shiny metallic surface of stainless steel.

The main aim of this research is to create the fabrics which can reduce the thermal infrared signature of human target, using stainless steel conductive yarn. The objectives of this study are to construct the fabrics by using polyester and stainless steel conductive yarns, to evaluate the physical properties of the samples and to investigate the concealing properties of the fabrics in the far infrared spectral range by using Thermal Camera. In this study, polyester and stainless steel conductive yarns are used to produce the thermal infrared camouflage fabric. An attempt is made to analyse the concealing behaviour of the fabrics produced with polyester and stainless steel conductive yarns in the far infrared spectral range. In this research, the thermal infrared camouflage fabrics are intended for use in the clothing items of the military application such as hats, jackets, trousers and boots.

2. EXPERIMENTAL PROCEDURE:

2.1 Collection of Yarn Samples

Polyester (PET) yarn is collected from the local market. Stainless steel conductive yarn is imported from Beijing Landingji Engineering Tech Co., Ltd.

2.2 Weaving of Fabrics

Five different samples of the fabrics, designated accordingly and listed in Table 2.1, are produced on Hand Loom.

Table 2.1. DESIGNATION OF FIVE DIFFERENT SAMPLES

Sample Code	Warp	Filling	Yarn Number (Tex)		Fabric Count	
			Warp	Filling	ends/cm	picks/cm
PS_1	PET yarns	Stainless steel conductive yarns	30	36	30	22
PS_2	PET yarns	Two stainless steel conductive yarns are inserted after every 25 PET yarns are inserted	30	30	30	22
PS_3	Two stainless steel conductive yarns are inserted after every 30 PET yarns are placed	Stainless steel conductive yarns	30	36	30	22
PS_4	Two stainless steel conductive yarns are inserted after every 30 PET yarns are placed	Two stainless steel conductive yarns are inserted after every 25 PET yarns are inserted	30	30	30	22
P_5	PET yarns	PET yarns	30	30	30	22

2.3 Testing the Fabric Samples

The physical properties of fabrics are determined according to the respective ASTM standards. All tests are carried out at standard atmospheric condition (20° ± 2°C, 65 ± 2% RH) in the Laboratory of Textile Testing and Quality Control of Department of Textile Engineering at Yangon Technological University. Air permeability of the fabric is determined in accordance with ASTM D 737 - 96. The value of the air permeability of the fabric is expressed in $cm^3/cm^2/sec$. The stiffness of the sample fabric is determined in accordance with ASTM D 1388 - 96.

2.4 Thermal Signature Concealing Testing

Before making the thermal signature concealing test, the fabrics are cut into small pieces of 7.5 cm in length and width. Fig.2.1 shows the experimental set-up for thermal signature concealing test. The prepared sample is laid on the metal plate when the temperature of the metal plate is reached at 34°C. And then, the thermal images of the prepared sample are taken by Ti 200 Fluke Thermal Camera after 0 minute, 5 minutes and 10 minutes. The effectiveness of thermal signature reduction is evaluated by the difference of seeming temperature (ΔT). The difference of seeming temperature can be calculated by the formula $\Delta T = T_h - T_{mat}$, where ΔT is the difference of seeming temperature, T_h is the temperature of the heated plate and T_{mat} is the temperature of sample laid on the heated plate. The bigger the difference of seeming temperature, the better concealing effectiveness of investigated material in the FIR spectral range.

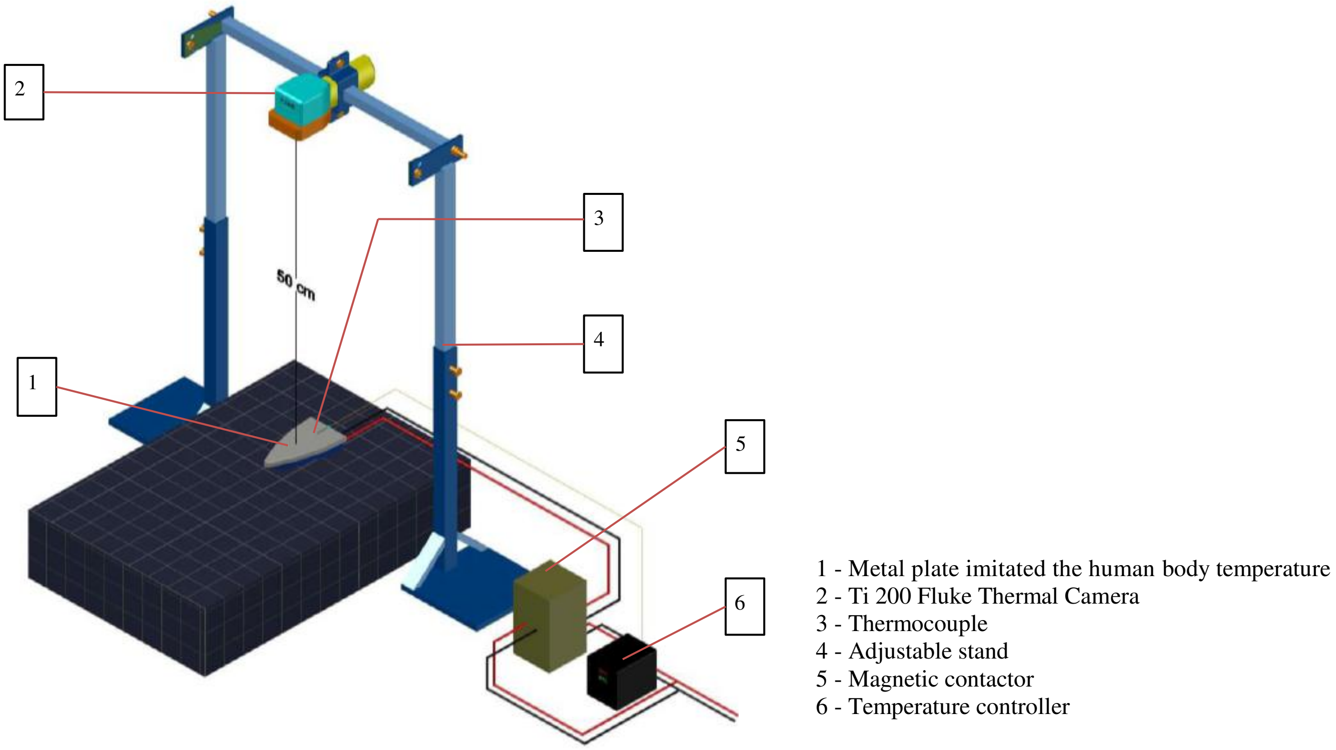


Fig.2.1 Experimental Set-up for Thermal Signature Concealing Test

2.5 Thermal Infrared Camouflage Jacket Making

After analysing the results of concealing properties of samples, the optimum samples are selected to produce thermal infrared camouflage jacket. The jacket is composed of two layers of sample fabrics in which inner layer is sample (P_5) and outer layer is sample (PS_2). Fig.2.2 shows the design of the thermal infrared camouflage jacket.

Fig.2.2 Design of Thermal Infrared Camouflage Jacket

2.6 Thermal Infrared Concealing Testing in Natural Environment

The views of thermal signatures of concealing object (human wears thermal infrared camouflage jacket) and non-concealing object (human wears normal cloth) are taken by thermal camera in natural environment at daylight and night. The distance between the thermal camera and the target is 5 metres. The images are transformed into 3D graphs by using SmartView 3.7.23.0 software.

3. RESULTS AND DISSCUSSIONS:

Table 3.1. COMPARISON OF PHYSICAL PROPERTIES AND THERMAL SIGNATURE CONCEALING TEST RESULTS OF SAMPLE FABRICS

Test			PS_1	PS_2	PS_3	PS_4	P_5	PS_2/ P_5	PS_2/ PS_4	PS_4/ P_5
Air Permeability ($cm^3/cm^2/sec$)			46.15	45.20	46.38	45.30	46.48	-	-	-
Cloth Cover Factor			22.89	22.12	22.49	21.97	22.12	-	-	-
Overall Flexural Rigidity (mg-cm)			45.57	43.82	48.85	48.00	46.98	-	-	-
Seeming Temperature (°C)	One Layer	0 min	31.0	31.1	33.1	32.5	32.9	-	-	-
		5 min	32.9	32.5	33.3	32.7	32.9	-	-	-
		10 min	32.8	-	33.1	-	-	-	-	-
	Two Layers	0 min	31.8	28.2	32.1	30.7	30.8	29.1	30.3	30.4
		5 min	32.9	32.0	33.2	32.7	32.0	32.3	32.8	32.8
	Three Layers	0 min	-	29.0	-	-	30.0	-	-	-
		5 min	-	32.1	-	-	32.0	-	-	-
Differences of Seeming Temperature (ΔT)	One Layer	0 min	3.0	2.9	0.9	1.5	1.1	-	-	-
		5 min	1.1	1.5	0.7	1.3	1.1	-	-	-
		10 min	1.2	-	0.9	-	-	-	-	-
	Two Layers	0 min	2.2	5.8	1.9	3.3	3.2	4.9	3.7	3.6
		5 min	1.1	2.0	0.8	1.3	2.0	1.7	1.2	1.2
	Three Layers	0 min	-	5	-	-	4.0	-	-	-
		5 min	-	1.9	-	-	2.0	-	-	-

3.1 Air Permeability Test Results:

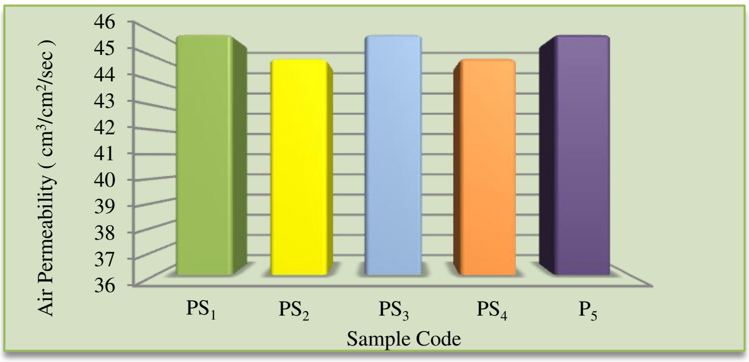


Fig.3.1 Air Permeability of the Produced Sample Fabrics

The results of the air permeability of the fabrics, as seen in Fig.3.1, show that the mean values of all samples do not differ significantly at 95% confidence limit. The reason is that the air permeability is affected by the fabric density.

Air permeability relates to the geometric structure of the sample fabrics. The geometric structure of the fabric mainly depends on the cloth cover factor. The cloth cover factor of all samples ranges from 21.97 to 22.89. All samples are nearly close to be the jammed structure because the cloth cover factor of the jammed structure fabric is about 23. As a result, the air permeability of all samples is low.

3.2 Fabric Stiffness Test Results

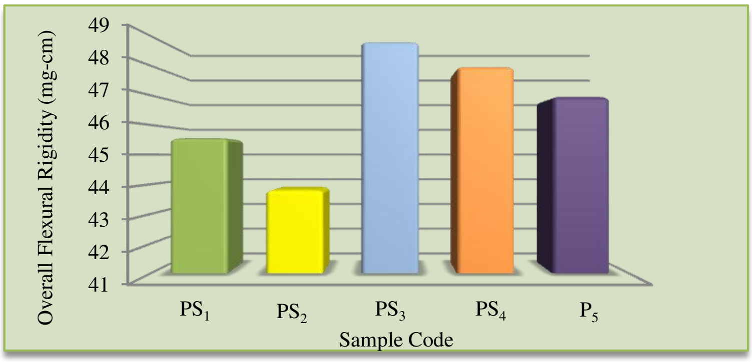


Fig.3.2 Overall Flexural Rigidity of the Produced Sample Fabrics

The thicker the fabric, the stiffer the handle. From Fig.3.2, it can be observed that the overall flexural rigidity of sample (PS_3) is the highest because the thickness of the sample is the highest among all samples. Good handle and drape can improve comfortability during wearing the camouflage clothing items. The sample (PS_2) is suitable for the camouflage clothing because the overall flexural rigidity of the sample (PS_2) is the lowest among all samples.

3.3 Thermal Signature Concealing Test Results of Sample Fabrics

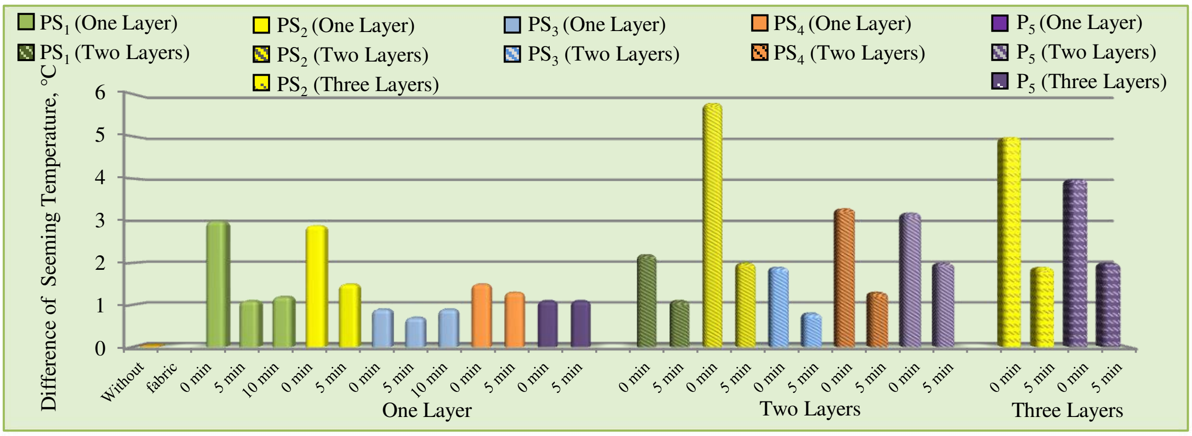
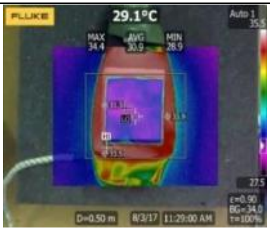
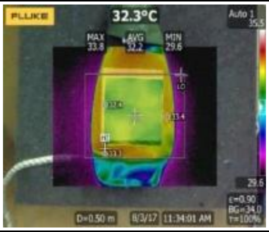
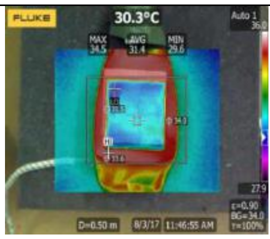
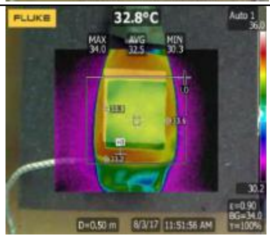
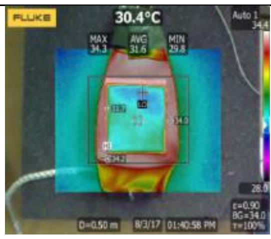
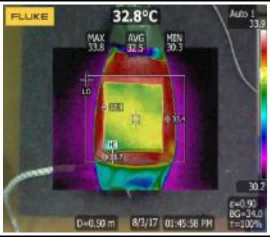


Fig.3.3 Difference of Seeming Temperature (ΔT) of the Layers of the Samples

Fig.3.3 shows the results of the differences of seeming temperature (ΔT) of the layers of the samples. The two layers of sample (PS_2) has the lowest seeming temperature and the highest amount of the difference of seeming temperature (ΔT) among all samples after 0 minute and 5 minutes. Thus, the two layers of sample (PS_2) has the best concealing property after 0 minute and 5 minutes. On the other hand, polyester fibres are better heat insulator than stainless steel fibres. Therefore, the two layers of sample (P_5) is the best heat insulator among all samples from 0 to 5 minutes.

Two Layers	The View of Sample on the Heated Plate	The View of Sample on the Heated Plate After 5 min
PS_2/P_5		
PS_2/PS_4		
PS_4/P_5		

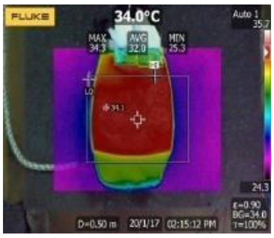
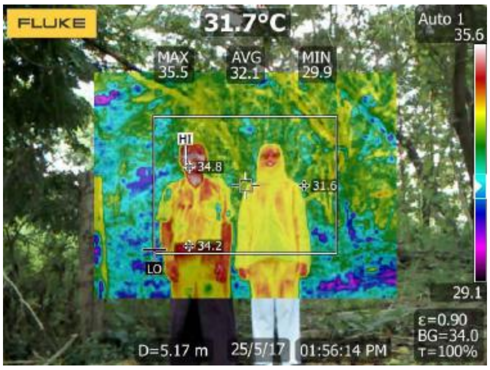
Metal Plate Imitating Human Body Temperature

Environment Background


Fig.3.4 Thermal Images of Samples (PS_2/P_5), (PS_2/PS_4), (PS_4/P_5), Metal Plate and Environment Background

The optimum samples are selected to produce the thermal infrared camouflage jacket. From Fig.3.4, it is observed that the sample (PS_2/P_5) gives the best concealing effect in the FIR spectral range because the inner layer of sample (P_5) prevents the human body temperature (34°C) and the outer layer of sample (PS_2) makes the target (32.3°C) interflow with environment (32.5°C).

3.4 Thermal Signature Concealing Test Results in Natural Environment



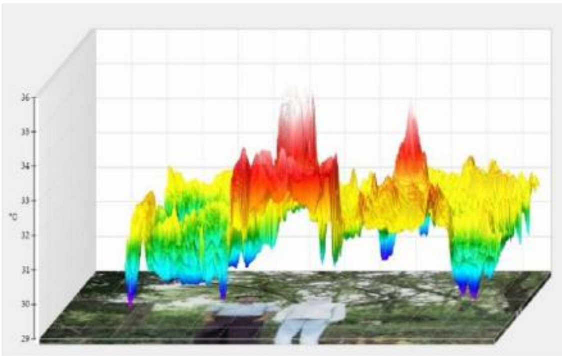
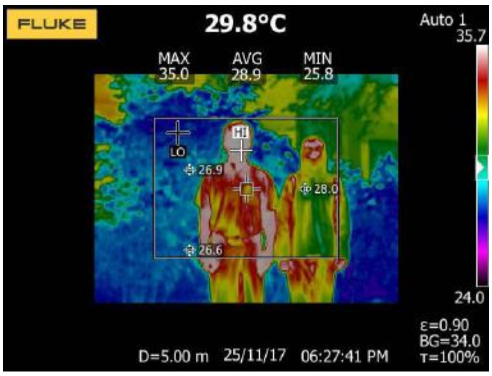


Fig.3.5 Thermal Image and 3D Graph of Seeming Temperatures in Natural Environment at Daylight: Human with Ordinary Outfit (Body in the Left) and Human with Concealing Outfit



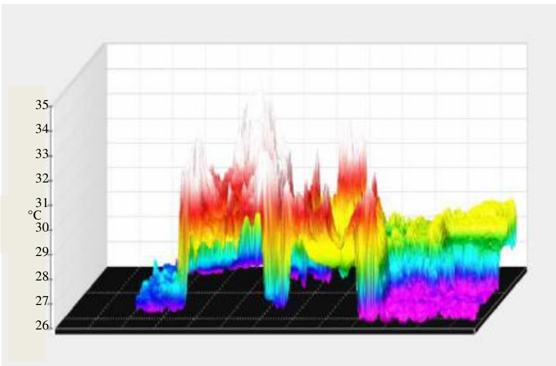


Fig.3.6 Thermal Image and 3D Graph of Seeming Temperatures in Natural Environment at Night: Human with Ordinary Outfit (Body in the Left) and Human with Concealing Outfit

The thermal images and 3D graphs of thermal signatures of concealing and non-concealing object (human) are presented at daylight and night as shown in Fig.3.5 and Fig.3.6. At daylight, it is seen that human with ordinary outfit is brightly visible, i.e. the seeming temperature is high (close to 34.8°C) while concealing outfit, produced from sample (PS_2/P_5), is minimizing contrasts of seeming temperatures between human with concealing outfit (31.7°C) and environment background (31.6°C). At night, it is seen that human with ordinary outfit is also brightly visible, i.e. the seeming temperature is high (close to 33.5°C) while concealing outfit is also minimizing contrasts of seeming temperatures between human with concealing outfit (28.5°C) and environment background (28.4°C). Therefore, the thermal infrared camouflage jacket can conceal the human in the FIR spectral range at daylight and night.

4. CONCLUSIONS:

Among five different samples, the sample (PS_2) is the best concealing fabric and the sample (P_5) is the best heat insulation fabric. Therefore, the sample (PS_2/P_5) is the best thermal infrared camouflage fabric in the FIR spectral range. The experimental results show that higher amount of stainless steel fibres incorporated in the fabric do not improve concealing properties of the fabrics. It is observed that insertion of the two stainless steel conductive yarns after every 25 polyester yarns inserted in weft direction can give the better concealing effect in this research.

The thermal images and 3D graphs of seeming temperatures in natural environment at daylight and night show that the concealing outfit, produced from sample (PS_2/P_5), can conceal the human body. The seeming temperatures of human with concealing outfit (31.7°C) and environment background (31.6°C) are closely identical at daylight. The seeming temperatures of human with concealing outfit (28.5°C) and environment background (28.4°C) are also closely identical at night. Hence, the concealing outfit can conceal the human body in the environment background at daylight and night. Therefore, the thermal infrared camouflage fabric by laying the sample (PS_2) on the sample (P_5) can be used in the clothing items of the military application such as hats, jackets, trousers and boots.

5. RECOMMENDATIONS:

From this study, it can be seen that the thermal signature of human target is reduced by using stainless steel conductive yarns because stainless steel has low emissivity. It is recommended that the other metal such as silver and aluminium should be used as metal conductive yarn for thermal infrared camouflage fabric according to the emissivity of each metal.

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