IOP Conference Series: Materials Science and Engineering

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IOP Conf. Series: Materials Science and Engineering **254** (2017) 072013 doi:10.1088/1757-899X/254/7/072013

Investigation of the influence of heat transfer on screen printed textile conductor

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Abstract. Two different textile substrates were screen printed with silver-based inks in order to be electrically conductive. In every textile four conductors were printed with different widths in order to investigate the influence of heat transfer on each conductor. This was done, by using the thermo graphic camera and through the evaluation of each conductor's profile. It was found that the conductors printed on the white textile had higher values of heat transfer compared to the other conductors printed on the dark textiles.

1. Introduction

Over the last years smart textiles have become popular as a concept. In order to manufacture these wearable textile systems, electroconductive textiles are needed. Electroconductive textiles can be achieved by using conductive fibres, yarns coatings, polymers or inks [1-14]. Nowadays the last method, the conductive inks, have found use in many smart applications such as printed circuit boards (PCBs), Radio-frequency identification (RFID tags), wiring boards, textile antennas, sensors, etc. [14-21]. These conductive printed lines show a rather high electric resistivity when silver inks were used during the screen printing process [9]. Wherefore with this research were given more information about the textile conductors in order to have the perfect smart textile, without hotspots.

Infrared thermography is the method used in this research, which is rapidly gaining popularity amongst the researchers in various fields like medicine, biology, material science, civil engineering, etc. Many researchers has explored the potential of infrared thermography to investigate several thermo physical phenomena like heat transfer, measurement of thermal properties, non-destructive testing (NDT), greenhouse gas exchange or diagnosis of diseases, as any of processes that leads to a variation in temperature of the object can be subjected to thermographic investigation. In textile research infrared thermography, is applied in different applications such as: synthetic fibre spinning, clothing comfort, non-destructive testing of composite, product development, mechanical property and failure analysis, thermal property, heat transfer and drying [13, 22-24].

In this paper were used two different textiles, where four conductors were screen printed with silver-based inks. In order to observe the thermal property and heat transfer a thermographic camera was used showing that the white textile has a higher value of the heat transfer for all four conductors compared to dark textiles. This research may help

2. Experimental work

In this study two woven textiles were selected, made of Cotton/Polyester (33/67%) and Polyamide (100% PA). The physical and mechanical properties were determined by ISO standards and are listed in the Table 1.

Table 1. Properties of applied textiles

Woven textile materials	Colour	Yarn density of fabric Warp (threads/cm)	Weft (threads/cm)	The type of textile weave	Basic weight (g/m²)	Specific heat (J/kg/KT)
Cotton/Polyester (CO/PES)	Dark blue	32	20	Twill 2/1	240	1166
Polyamide (PA)	White	45	32	Twill 2/2	99	1600

The conductive ink used for these textiles was provided by Henkel and the screen printed method is used [9]. The design has four lines with different width and a square as reference (Figure 1).

	l_1	l_2	l_3	l_4	l_5 (mm)	l_6	l_7	l_8	l_9
Design	20	5	10	4	5	3	2.5	3	10
Textile 1 (CO/PES)	20.5	4.5	11	3.5	6	3	3	2.5	10
Textile 2 (PA)	20	4.5	10.5	3.5	5.5	3.5	2.5	3	10

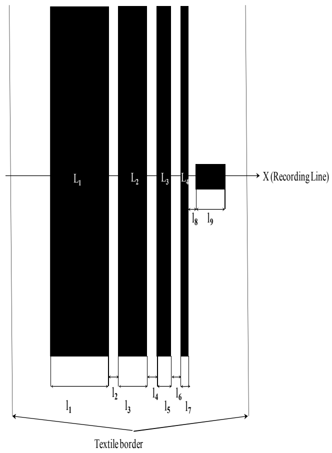

Figure 1. Design and parameters for the conductors

3. Method for thermal analysis

In order to analyse the thermal properties of the printed samples a thermographic camera FLIR T420 25°, is used.

The samples were hanged and a current was supplied to each printed line separately, from a DC power supply (EL301R Power Supply). The measurements were completed at room temperature.

Each line was measured separately from the others. On each line two contacts were glued with electroconductive glue on the both edges of the conductive sample, in order to have a good electroconductive contact.

The current supplied was increased from 0.200, 0.500 to 1.050 A and the voltage is measured. To stabilize the temperature, was waited for 15 minutes and this was recorded with the thermal camera.

The data were collected for the line X (recording line) (see figure 1) and the profiles for the two transmission lines were taken.

4. Results and Discussion

After the evaluation of the profiles for each transmission line (L_1, L_2, L_3 and L_4) some calculations of the slopes were done in order to calculate the total heat transfer and the thermal conductivity, concluding with theoretical calculations of the slopes.

All transmission lines of the two textiles were given the same current, so they will have the same heat energy (depending from the width) as a result of conductive heat transfer. Regarding to the color of

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textiles, the white will radiate the heat to surrounding printed transmission lines, more slowly than the dark textiles. This can be explained by the fact that dark surfaces absorb radiant energy while white ones reflect it. The profiles for two conductors are shown in Figure 2.

Figure 2. Profiles for the four conductors

After the evaluation of the profiles some theoretical calculations of the slopes were done:

$$L = \frac{0,4 \quad (x_2-x_1)}{l(\quad _1 - l(\quad _2} \tag{1}$$

Where: x1 and x2- the start and the end point of the slope
In order to calculate the total heat transfer the equation (2) is used:

$$h = hc + hr \tag{2}$$

Where:
hc – heat transfer convection
hr – heat transfer radiation

$$h_c = 1{,}485 \left(\frac{\Delta T}{H}\right)^{0,2} \tag{3}$$

$$hr = 4\sigma \quad T3 \tag{4}$$

ΔT - the average temperature difference
H - The height of textiles sample = 0,235m
σ - Stefan Boltzmann constant = 5.6703 × 10-8 (Wm-2K-4)
T – Absolute temperature in Kelvin
In order to find the thermal conductivity the formula (4) is used:

$$L = \sqrt{\frac{kt_S}{2h}} \Rightarrow k = \frac{2hL^2}{t_S} \tag{5}$$

Where: ts-the thickness of the textile

In the Figure 3 the profiles for the printed textile 1 are shown. Each profile is evaluated separately by drawing slopes, such as Line 1-1, Line 1-2 and Line 1-3 (Figure 4). The first number of the Lines shows the printed conductor (Figure 1) and the second number the slopes of the profile in evaluation.

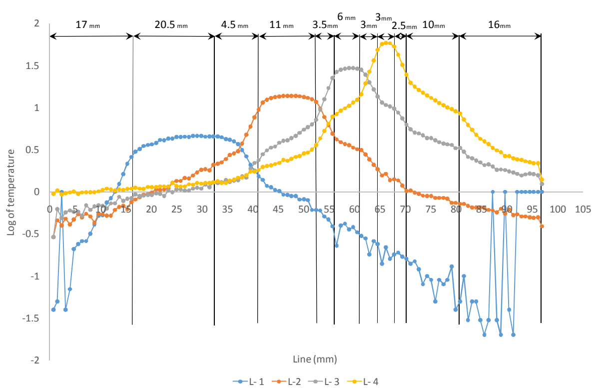


Figure 3. Four profiles for the Textile1

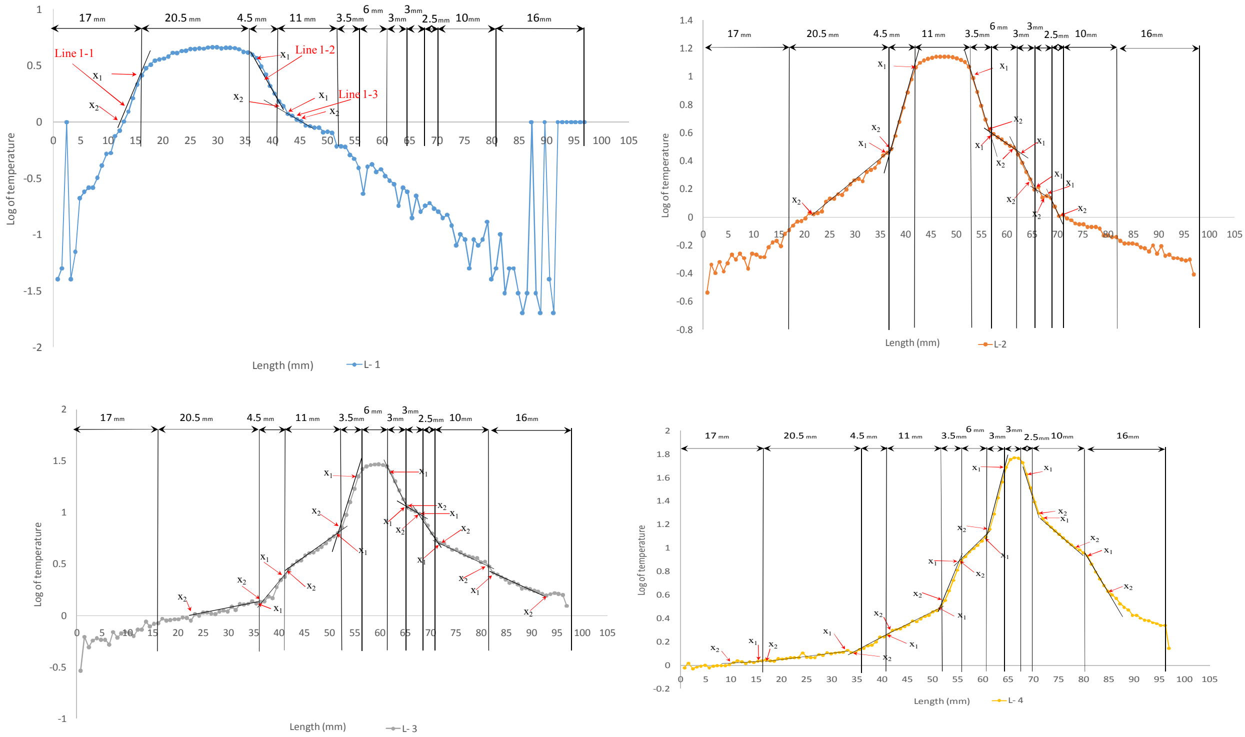


Figure 4. Evaluation of the profile through the slopes for the conductors 1, 2, 3 and 4 of the Textile 1

In the Figure 5 the profiles for the printed textile 2 are shown. Each profile is evaluated as explained above.

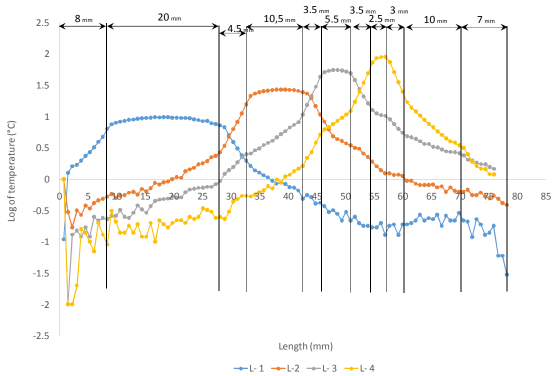
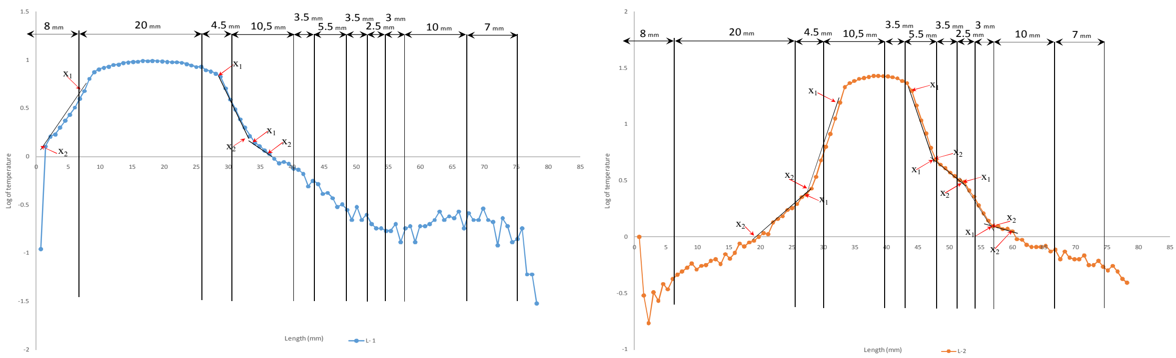


Figure 5. Four profiles for the Textile2



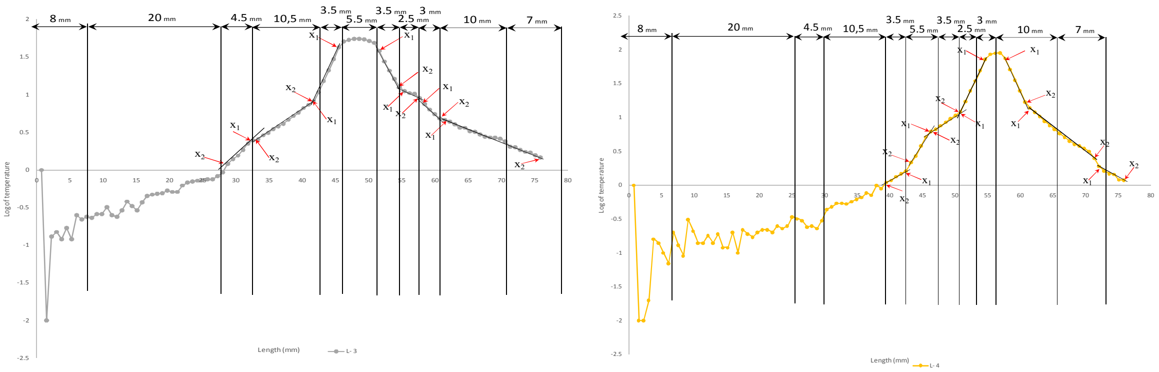


Figure 6. Evaluation of the profile through the slopes for the conductors 1, 2, 3 and 4 of the Textile 2

In the table 2 and 3 are shown the results of the theoretical calculations of the slopes, done after the evaluation of the profiles for each conductor (L_1, L_2, L_3 and L_4).

Table 2 and 3. Theoretical results of the slopes for Textile 1 and Textile 2

Textile 1							
Nr	x_1 (mm)	x_2 (mm)	log T_1	log T_2	H (W/m^{-2}°C)	L^2 (mm)^2	k (W/m·K)
Line 1-1	15,35	12,93	0,33	0,00	9,27	10,17	0,44
Line 1-2	37,17	42,02	0,57	0,14	9,27	24,42	1,05
Line 1-3	42,82	45,25	0,07	0,01	9,27	279,10	12,04
Line 2-1	42,02	37,17	1,07	0,48	10,76	13,13	0,66
Line 2-2	36,36	21,82	0,46	0,02	10,76	208,71	10,45
Line 2-3	52,52	56,56	1,07	0,62	10,76	15,47	0,77
Line 2-4	57,37	61,41	0,59	0,50	10,76	333,89	16,71
Line 2-5	61,41	64,64	0,50	0,27	10,76	38,22	1,91
Line 2-6	65,45	67,87	0,20	0,15	10,76	522,65	26,16
Line 2-7	68,68	70,30	0,14	0,01	10,76	30,05	1,50
Line 3-1	55,75	52,52	1,35	0,85	12,68	8,04	0,47
Line 3-2	51,71	42,02	0,80	0,45	12,68	143,05	8,44
Line 3-3	41,21	37,17	0,37	0,14	12,68	54,32	3,20
Line 3-4	36,36	23,43	0,13	0,01	12,68	2152,81	127,01
Line 3-5	62,22	65,45	1,39	1,06	12,68	17,87	1,05
Line 3-6	65,45	67,87	1,06	0,99	12,68	213,69	12,61
Line 3-7	67,87	72,72	0,99	0,69	12,68	50,92	3,00
Line 3-8	72,72	81,61	0,69	0,48	12,68	319,21	18,83
Line 3-9	82,42	92,92	0,41	0,19	12,68	429,78	25,35
Line 4-1	64,64	61,41	1,69	1,16	15,82	7,09	0,52
Line 4-2	60,60	55,75	1,09	0,89	15,82	108,59	7,99
Line 4-3	55,75	52,52	0,89	0,55	15,82	17,14	1,26
Line 4-4	51,71	42,01	0,50	0,28	15,82	421.75	31.4
Line 4-5	41,21	33,94	0,26	0,11	15,82	443,10	32,61
Line 4-6	33,13	17,78	0,13	0,04	15,82	5485,61	403,72
Line 4-7	16,16	10,50	0,04	0,02	15,82	23559,09	1733,84
Line 4-8	68,68	71,10	1,63	1,29	15,82	10,05	0,74
Line 4-9	71,91	78,38	1,25	1,03	15,82	161,29	11,87
Line 4-10	80,80	84,84	0,93	0,63	15,82	33,74	2,48

Textile 2							
Nr	x_1 (mm)	x_2 (mm)	log T_1	log T_2	H (W/m^{-2}°C)	L^2 (mm)^2	k (W/m·K)
Line 1-1	7,590	1,518	0,678	0,103	10,19	21,02	3
Line 1-2	28,842	33,396	0,827	0,212	10,19	10,34	2
Line 1-3	34,155	36,432	0,139	0,029	10,19	80,78	13
Line 2-1	32,637	28,083	1,193	0,428	12,43	6,68	1
Line 2-2	27,324	19,734	0,372	0	12,43	78,48	15
Line 2-3	44,022	47,817	1,296	0,684	12,43	7,25	1
Line 2-4	47,817	51,612	0,684	0,502	12,43	81,97	16
Line 2-5	51,612	56,925	0,502	0,0934	12,43	31,88	6
Line 2-6	56,925	59,961	0,0934	0,049	12,43	881,49	169
Line 3-1	45,54	41,745	1,692	0,909	15,57	4,43	1
Line 3-2	41,745	33,396	0,909	0,408	15,57	52,36	13
Line 3-3	32,637	28,842	0,394	0,082	15,57	27,89	7
Line 3-4	51,612	54,648	1,58	1,102	15,57	7,61	2
Line 3-5	55,407	57,684	1,045	0,955	15,57	120,68	29
Line 3-6	58,443	60,72	0,877	0,684	15,57	26,24	6
Line 3-7	61,479	75,9	0,667	0,164	15,57	154,97	37
Line 4-1	54,648	50,853	1,858	1,085	19,54	4,54	1
Line 4-2	50,853	46,299	1,085	0,795	19,54	46,49	14
Line 4-3	46,299	43,263	0,795	0,338	19,54	8,32	3
Line 4-4	42,504	39,468	0,2121	0,041	19,54	59,36	18
Line 4-5	57,684	60,72	1,87	1,228	19,54	4,22	1
Line 4-6	61,479	71,346	1,141	0,394	19,54	32,89	10
Line 4-7	72,105	75,9	0,276	0,075	19,54	67,21	20

As it can be seen at the tables, 2 and 3, textile 2, which has a white background show to have a higher value of the heat transfer for all four conductors, compared to the other two textiles. This can explain by the fact that dark surfaces absorb radiant energy while white ones reflect it.
All conductors of the two textiles were given the same current, so they will have the same heat energy (depending from the width) as a result of conductive heat transfer. Regarding to the colour of textiles, the white will radiate the heat to surrounding printed conductors, more slowly than the dark textiles.

In table 4, is given a summary of the heat transfer for all the textiles. Here, one can observe that for the two textiles, the heat transfer increase with the decrease of the conductor width. As it can be seen the Line 4 with a width of max 3 mm has the highest values than Line 1 with a width of max 20.5 mm.

Table 4. Total heat transfer for the textiles

	h (W/m^{-2}°C)	
	Textile 1	***Textile 2***
Line 1	9,27	10,19
Line 2	10,76	12,43
Line 3	12,68	15,57
Line 4	15,82	19,54

5. Conclusion

In this paper the investigation of the influence of heat transfer on screen printed textile transmission lines is presented. Based on the experimental results of the two textile screen printed transmission lines, was conclude that textile 2, which has a white background show to have a higher value of the heat transfer for all four transmission lines, compared to the textile 1.

Moreover was observe that the heat transfer increase with the decrease of the conductor width.

So it is important to mention that in order to have the right textile conductors, one has to make the right combination of textile materials, design and conductive inks.

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