

# Characterization of the conducting threads

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## 1. Abstract:

The report describes resistance measurement of some novel conducting threads and the measurement method. All of the measurements were performed in the EMC Lab at SP Technical Research Institute of Sweden, Borås. The conducting threads were received from the Polymer Laboratory at School of Engineering, University of Borås. We measured two types of conducting threads (we named them A for PE-1292 and B for PE-1304) with a number of different draw ratios. The draw ratios were 4/24, 4/20, 4/16, 4/12 and 4/8. And they were named A1, A2, A3, A4 and A5 for sample PE-1292 of the draw ratios 4/24, 4/20, 4/16, 4/12 and 4/8 respectively. The same thing was applied for sample B. We measured 12 samples for each draw ratio. The conductive additive used for the two different types of threads was Carbon Black.

The resistance was measured using two different methods: The two terminal measurement method and the four terminal measurement method. A result from the comparison of the two methods was that the two terminal measurement method provided more information than the four terminal method. There seemed to be no advantage using the four terminal method at all, for the studied resistance range.

We also studied the non-linear behaviour of the resistance as function of the applied voltage as well as the thermal breakdown of the different samples of conducting fibre and the result is the samples are not conducting up to some lower applied voltages but they are conducting from a specific higher voltages. The large percentage of the samples could not bear the highest applied voltage 500V. They are showing the lower conductivity from the lower draw ratios to higher draw ratios.

Keywords: Conducting fibres, two terminal resistance measurement method and four terminal resistance measurement method.

## 2. Introduction:

Smart textile: Textiles those are able to sense stimuli from the environment, to react to them and adapt to them by integration of functionalities in the textile structure. The stimuli/response can have electrical, thermal, magnetic or other origin.<sup>16</sup>

A conductive textile fiber is a material in fiber form

(long and very, very thin). Synthetic fibres have normally a very low conductivity. Other requirements are that the fibre shall be suitable for textile applications and for the different production steps in textile industry. If the end product needs to be washable then the conductive fibre also need to be washable. Another important aspect on the conductive fibre is that it shall not be harmful to the environment.

Known applications areas for conductive fibres are for example antistatic, ESD (Electro statically Dissipative) shielding, heating and power transfer. Other application areas for conductive fibres might be as sensors or to propagate signals. It is going to be used in medical textiles as well.

There is at least four ways of producing conductive fibers:

1. Melt spinning (mixing carbon black, metal powders or conductive polymers with thermoplastics).
2. Dry spinning.
3. Coating of non conductive materials with different conductive materials. For instance-coagulated polymers, carbon black etc.
4. Inkjet printing.

The increase of conductivity can be obtained by adding additives to the bulk material either homogenously distributed or for example as a surface coating. Metal is usually not infused but added as a very thin conducting threads to the non-conducting threads, where the amount of metal thread can be adjusted to the need of the manufacturer.<sup>1</sup>

## 3. Conductivity:

With the electrical safety and the non linear behaviour of the ESD protective garments in mind, we can categorize textiles according to table 1 and table 2. The voltage in table 1 and table 2 is the applied voltage for characterizing the resistance of a textile.

**Table 1: Summary on approximate resistance and voltage applications.**

Voltage(V) Resistance (Ohm)	0.1	1	10	100	1000	Class
<0.01	S+P	S+P	S+P	S+P	S+P	Conductive
0.01-1	S+P	S+P	S+P	S+P	S+P	
1-1 k	S+P	S+P	S+P	S+P	S+P	
1 k - 100 k	"S-"	S	S+P	S+P	S+P	Dissipative
100 k - 100 M	ESD	"S-"	"S-+ ESD	"S-+ ESD	S+P	
100 M - 10 G	ESD	ESD	ESD	ESD	"S-"	
> 10 G	ESD	ESD	ESD	ESD	ESD	Insulating

**Table 2: Disturbance and electrical safety issues for conductive textile.**

Voltage (V) Resistance (Ohm)	0.1	1	10	100	1000	Class
<0.01			£	\$	\$	Conductive
0.01-1			£	\$	\$	
1-1 k			£	\$	\$	
1 k - 100 k	*		£	\$	\$	Dissipative
100 k - 100 M	*	*	*	£	£	
100 M - 10 G	*	*	*	*	£	
> 10 G	*	*	*	*	*	Insulating

S Signal can be transferred.  
 P Power can be transferred.  
 ESD ESD protective fabrics.  
 \* Special application is possible, but the currents are likely to be distributed by static electricity.  
 £ Voltage not directly dangerous, however can be unpleasant.  
 \$ Voltage dangerous to personnel, special safety procedure must be applied.

The different regions indicated in the table 1 and 2 are only approximate and one can only be used as guide line. The label "S-" is used for that signal transfer may be possible; however one might not be able to use the textile as a conventional conductor except for the lowest resistance class.

The black area in the left upper corner of table 2 is

resistance that one should aim at.<sup>3</sup>

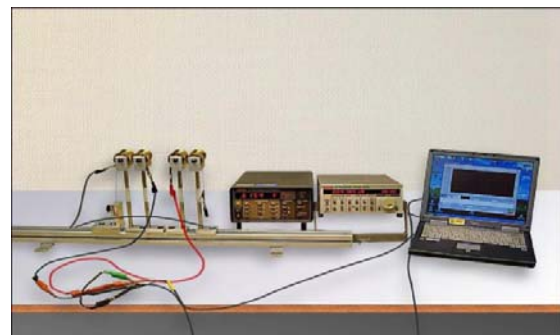
**4. Experimental set-ups:**

In our experiments we have measured the resistance of several samples. The samples are made from carbon black. The diameters of the threads were 0.2 mm approximately. We made twelve measurements for a sample to get accuracy.

*\*487 Picoammeter/Voltage Source:*  
**Brand name:** Keithley, Range: Up to 500 V, 2 mA.  
**Function:** By this equipment, we can measure I (Amp), R (Ω), Voltage (V). In addition we can supply electricity to the tested samples by this. This instrument can measure the maximum voltage difference 500 V and maximum current 2 mA. This equipment is shown in picture 1. It is situated third to the right in picture 1.

*\*Electrometer:*  
**Brand name:** Keithley 617, Range: Upto 250 V, 2 mA.  
**Function:** It cannot supply electricity to the tested samples like picoammeter. But we can measure I (Amp), R (Ω), U (Volt) by this instrument. This instrument can measure the maximum voltage difference 250 V and maximum current 2 mA. This instrument is shown in picture 1 second to the right.

*\*Multimeter:*  
**Brand name:** Fluke, True RMS multimeter.  
**Function:** By Multimeter we can measure current I (Amp), Voltage U (Volt), Resistance R (Ω) etc. Not shown in picture 1.



**Picture 1: The experimental set-up is presented.**

*\*Fixture:*  
 This instrument made at SP workshop. The fixture was made by brass metal. It is used to hold the tested threads and to connect the crocodile clips with the threads. With this fixture a 50g dead weight is attached. We could not use the 50 g dead weight for our tested samples. Because the threads could not bear this weight and extended on this weight

and broke. So we used an 11.0 g crocodile clip for that.

We use alcohol to remove the grease from the fixtures when we received it from the SP Workshop. The reason is that grease can affect the resistance values for the experiment. We were ensured of removal of grease from the Fixture by measuring resistance of the brass made Fixture on its different places by Multimeter. The instrument is shown in the picture 1 first to the left.

*\*Silver conductive paint:*

**Brand name:** Electrolube.

**Function:** To contact the threads with fixture. It should be shaken properly before it is used and we need to use a wood stick to use over fixture.

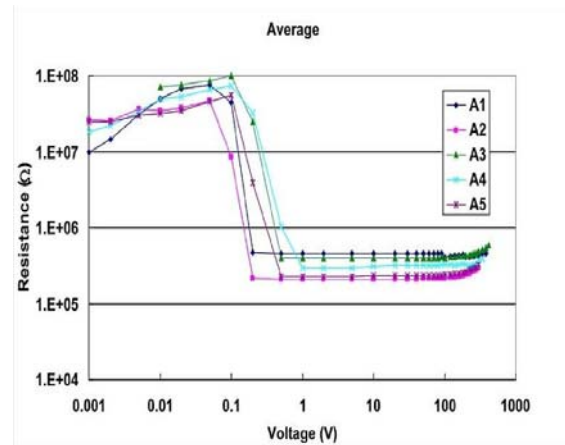
*\*Crocodile clips:*

**Function:** To contact the electrical instrument with the thread.

We could not use the 50 g dead weight for our tested samples. Because the threads could not bear this weight and extended on this weight and broke. So we used a less weight crocodile clip for that.

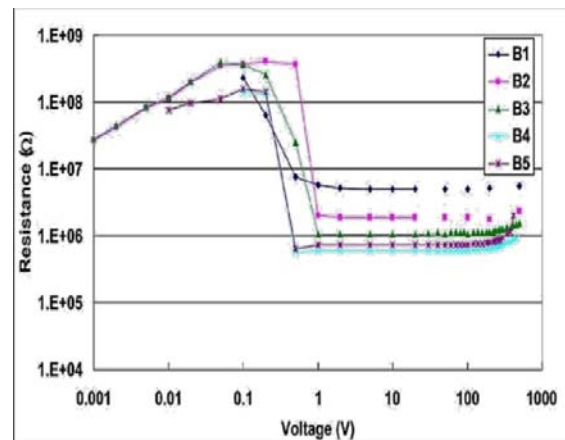
## 5. Experiment of the conducting threads characteristics identification:

We have faced many difficulties as well as uncertainty to measure the resistance of the samples by the 2-point and the 4-point measurements. For example, we are not sure about the resistance(R) of the brass made fixtures, crocodile clips and they are also contributing to our results. In addition, we do not know the actual conductivity of the silver paint. As the resistance(R) of our conductive thread is high, it is acceptable to measure the resistance by this set-up. The test was performed in the ESD lab where the relative humidity was  $(12\pm 3)\%$  and the temperature was  $(23\pm 2)^\circ\text{C}$ . We have done many experiments to make dependable information about conducting threads characteristics. I am focusing on few of them in this report. In the experiment part, we will discuss about the general description about pictures. In result part, we shall discuss our research findings.



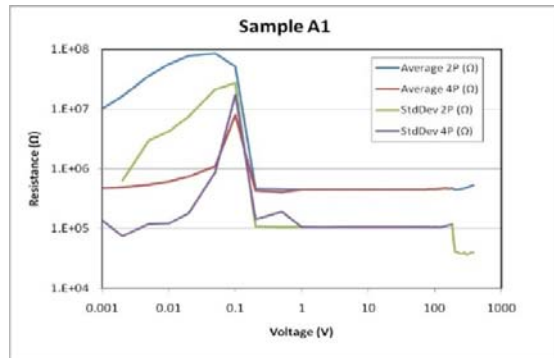
**Figure 1:** The graph describes the resistance (R) versus applied voltage (U) curve for the samples PE 1292, Draw ratio- 4/24 (A1), 4/20 (A2), 4/16 (A3), 4/12(A4), 4/8(A5). In X-axis we have shown different voltages and in the Y-axis we have plotted average of the above described 5 samples resistance.

In figure 1, we have compared the average resistance (R) as a function of applied voltages (U) for the five samples (A1, A2, A3, A4, and A5), they can be distinguished by their different colours. The highest applied voltage for Picoammeter was 500V. We recorded the current (I) for all applied voltages and calculated the resistance(R) by applying the Ohm's law ( $U=IR$ ). The scale of the X-axis (applied voltage) is logarithmic. The average resistance(R) of the five samples were pointed in the graph for the different voltages (range: 0.001-500V). We have added the lines only to guide eye.



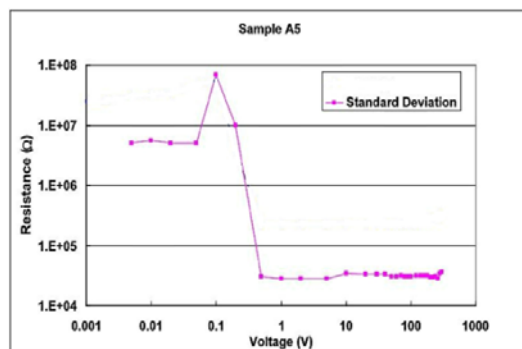
**Figure 2:** The Graph describes the resistance (R) versus voltage (U) curve for the samples PE-1304 with different draw ratios 4/24(B1), 4/20(B2), 4/16(B3), 4/12(B4), 4/8(B5). In X-axis we have shown different voltages and in Y-axis we have plotted the average resistance for the above described 5 samples.

In figure 2, we have compared the average resistance ( $R$ ) of the five samples (B1, B2, B3, B4, and B5) with different colours as a function of applied voltages ( $U$ ). The highest applied voltage was 500V for Picoammeter. We recorded the current ( $I$ ) for all applied voltages and calculated the resistance( $R$ ) by applying the Ohm's law. The scale of the X-axis (applied voltage) is logarithmic. The average resistance ( $R$ ) of the five samples were pointed in the graph for the different voltages (range: 0.001-500V).We have added the dots to guide the eye.

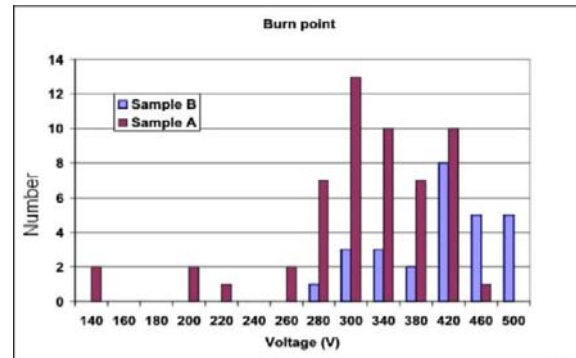


**Figure 3: Four versus two point measurements. The resistance is presented as function of the applied potential; both the average value and the standard deviations are presented.**

It is clear from figure 3 that it is difficult to interpret the results for both four-point and two-point measurements for lower applied voltages. However when the voltage is sufficiently high, in this case over 1 V, then the results are consistent as is seen in figure 3.

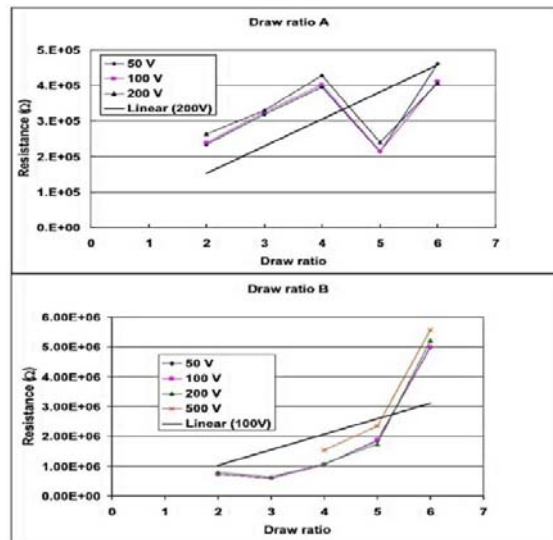


**Figure 4: The graph describes the resistance ( $R$ ) versus applied voltage ( $U$ ) curve for sample A<sub>5</sub>. The red line describes the standard deviation of the 12 samples resistance value when it is plotted according to respective voltages.**



**Figure 5: The Graph illustrates the number of burnings occurred at a specific voltage for the five samples referred to as sample A colour red and for the 5 samples of B colour blue.**

In figure 5, we have shown the number of burnt samples for every specific voltage, for both our two samples A (colour red) and sample B (colour blue). On the X-axis we have presented the applied voltages ( $U$ ) and in the Y-axis we have shown the number of burnt samples for every applied voltage ( $U$ ). The sample A burnt on average at around 300V and sample B burnt on average around 420V.



**Figure 6: The upper part of the graph illustrates the resistance ( $R$ ) versus Draw ratio line for the Sample A and lower part is for the sample B. In X-axis we have shown different draw ratios and in Y-axis we have plotted their resistance in the voltages 50, 100, 200, 500V. The black line is only guide for the eye and corresponds to the classical resistance of a thread.**

In figure 6, we have described the resistance ( $R$ ) versus draw ratio. The upper graph shows sample A and the lower graph shows sample B. In the X-axis we have plotted different draw ratios and in the Y-axis resistance ( $R$ ).We have observed this affect of draw ratios on few selective voltages (50,100,200V) for the sample A and (50,100,200,500V) for the

sample B. Including that, there is a Black linear line (200V for sample A and 100V for sample B) in both figures and those lines are referred to the theoretical sample.<sup>3</sup>

## 6. Results:

In the figure 1 and 2, If we observe these graphs, the resistances (R) were non-linear and high ( $10^7$  to  $10^8 \Omega$  approximately) for the lower applied voltages (from 0.001 to 1 V). It indicates that threads are not conductive on lower applied voltages. But interestingly, from the 1 V to 500 V the situation changed dramatically. The resistance was going to be low (around  $10^5 \Omega$ ) and linear. It means that threads are conductive on higher voltages. The reason may be that, the density of the carbon black on the fiber is not sufficient to make the fiber conductive on the lower applied voltages. It is mentionable that carbon black is the main contributor to make the fiber conductive. It is mentionable that in the last end of the lines in the graphs the resistance went to little bit high. A probable reason for these slight increases in resistance is the thermal effects in the fibre during voltage increase.

In this figure 3, we have presented the data of two points and four points' method together. From the graph, we see that for the lower voltages (from 0.001 V to 1 V) threads are not conductive. Because the resistance was too high (from  $10^7$  to  $10^8 \Omega$  approximately) as well as non-linear. In addition, the data's were fluctuating too much. But the resistance was going to be significantly lower (around  $10^5 \Omega$ ) for the higher applied voltages (from 1 V to 500 V) and it was showing linear behavior simultaneously. As a result, the standard deviation was high for the lower applied voltages (from 0.001 V to 1 V) that was  $4 \times 10^7 \Omega$  approximately. On the opposite side, for the higher applied voltages (from 1 V to 500 V), the standard deviation lines were going to be linear and very low (around  $10^5 \Omega$ ).

In figure 4, the standard deviation was high between the 12 samples (A5) measurement for specific voltages due to the lower applied voltages (from 0.001 V to 1 V) and that was  $4 \times 10^7 \Omega$  approximately. On the opposite side, for the higher applied voltages (from 1 V to 500 V), the standard deviation lines were going to be linear and very low (around  $10^5 \Omega$ ).

In the figure 5, we have shown the number of burning occurred on a specific voltage for our samples A (red) and B (blue). The number of burning points was significantly higher on 300 V that was 13 for the sample A. But on 340, 380 and 420V the burning points were also very high and

they were 10, 7 and 10 respectively. But it is very low for the voltages 140, 200, 220, 260 and 460 V. On the other hand, the burning points were high on the 420 V that was 8 and for the 460, 500 V the number of burning points were 5 for the sample B. But it was few for the 280, 300, 340 and 380 V and the numbers were 1, 3, 3 and 2 accordingly.

In the figure 6, we showed the resistance (R) versus draw ratio graphs for the samples A and B for some special voltages. The black lines are only guide for the eye and referred to the theoretical sample. If we describe the figure of sample A, the resistance was low ( $2.5 \times 10^5 \Omega$ ) for the draw ratio 2 but it increased sharply for the draw ratios 3 and 4 ( $3.2 \times 10^5 \Omega$  for draw ratio 3,  $4.2 \times 10^5 \Omega$  for draw ratio 4 approximately). Then it decreased exceptionally for the draw ratio 5 ( $2.1 \times 10^5 \Omega$  approximately). But again it rose acutely for the draw ratio 6 ( $2.1 \times 10^5 \Omega$  to  $4.1 \times 10^5 \Omega$  approximately). The probable reasons for this unusual behavior of not increasing the resistance by increased draw ratio:

\*The fiber may be amorphous in nature before drawing and the carbon black on the surface was not aligned but when the drawing was done the fiber became crystalline and carbon black was arranged as a result the resistance decreased. The temperature can affect as well. If the temperature was low during operation, it will take low time to dry so carbon black will be less dispersed and the fiber will be more conductive. (It will happen if the fiber was crystalline. If it was amorphous, the opposite will happen).

On the other hand, if we want to explain the sample B graph, the resistances were very low on draw ratios 2 and 3 ( $0.8 \times 10^6 \Omega$  and  $0.7 \times 10^6 \Omega$  consecutively). Then it inflates gradually from the draw ratio 3 to 4 (from  $0.7 \times 10^6 \Omega$  to  $1 \times 10^6 \Omega$  approximately) and 4 to 5 ( $1 \times 10^6 \Omega$  to  $1.8 \times 10^6 \Omega$ ). But it increased dramatically from the draw ratio 5 to 6 (from  $1.8 \times 10^6 \Omega$  to  $5 \times 10^6 \Omega$  approximately).

## 7. Conclusion:

The conductivity is an important issue in the smart textile. In this experimental work, we measured the resistance of conductive threads. We got the various conductive samples from PhD student Azadeh Soroudi and she made these conductive samples in collaboration with professor Mikeal Skrifvars at the University of Borås. The conductive additive carbon black was added with the samples. We used different instruments at the SP technical research institute of Sweden to measure the resistance of the novel conducting threads. We worked in a room at SP where the temperature,

humidity was controlled and the room was known as ESD lab. The samples were highly resistive as well as non-linear for low voltages. But the samples showed lower resistance and linear behavior for higher applied voltages. The most of our samples burnt before the applied voltage of 500 V. The digits on the screen of the instruments were fluctuating too much before burning that gave us a signal of burning time. The five samples of B did not burn at 500 V. On the other hand, no sample of A was intact at 500V. We expected that the resistance will behave linearly from low to high draw ratios, but we did not see that. We expect that for high draw ratios, the conductive materials of the samples can disperse more and the samples will become more resistive. We used the four terminal and the two terminal measurement methods for measuring the resistance of samples. Both techniques gave similar results for higher voltages. We got the advantage of four terminal measurements over two point measurement method. However in the case of sample A and sample B we saw no such advantage. We used the silver conductive paints for contacting the samples with the fixture properly but we are not sure about the actual conductivity of this silver paints and its effect on the threads. We hope that we will work on this property in the next part of this project.

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