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# APPROACH ON MEASURING THE SURFACE RESISTIVITY OF ESD-FABRICS

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***Abstract***–The paper mainly deals with the influence of the applied measuring voltage on the surface resistance/resistivity of 19 fabric samples, being representative for the various technical solutions of obtaining static dissipative textiles. There were chosen for exemplification six samples with various behaviors regarding the relationship between the increasing excitation DC voltage and the measured results. Based on the Keithley’s hard and soft infrastructure, it was developed the Alternating Polarity method, with a sweep of voltage, nine equal steps from 90V to 990V. There were plotted graphs presenting the different trends of the material response at various excitation voltages. The significant number of performed measurements allowed us to pick up and test possible explanations or just hypothesis for different and sometime unexpected performances of the conductive insertion technologies, aiming to transform the fabrics from very good insulators into static dissipative materials.

***Keywords***: resistivity, dissipative textile, alternating polarity

## 1. TRANSFORMING TEXTILE FROM GOOD TO POOR INSULATORS

A modern challenge is to transform some textile materials, basically very good insulators, in materials with anti-static and in the same time, screening properties. Other words, these fabrics should receive, for some specific applications, conductive properties. Of course, becoming too good conductors presents an unacceptable risk: to produce short-circuits and to reduce the electric safety of the persons wearing them.

The general theoretical solution is the insertion of some “wires” with conductive properties inside the classical fabrics. The most significant parameter assessing the conductive properties of the insulators is the surface (superficial) resistivity. The main target is to develop technologies aiming to decrease this initially high surface resistivity below $10^{12}\Omega$ /square, while remaining higher than $10^{5}\Omega$/square. These somewhat approximate values are generally accepted by the specialists working in the field, being stated since 1988 in American Standard EIA 541, focused on packaging materials for ESD sensitive items [1] or in the IEC 61340-5-1 standard dealing the protection of electronic devices against static accumulation and consecutive discharge [2]. These static dissipative materials should guarantee a decay time for the triboelectrically generated static charges less than 2 seconds, as it is settled in FED-STD-101C [3], the well-known American standard that unifies the test procedures for assessing the dissipative behavior of some materials, removing pointless differences in the world wide testing procedures and aiming to provide comparable measurements for the same material. For homogeneous materials, the direct proportional relationship between surface resistivity and the time of decay was demonstrated [4]. Unfortunately, the fabrics with any type of conductive insertions are basically non-homogeneous; the correlation must be treated in a different manner, a decent approach being developed in [5].

For measuring the surface and (associated) bulk, volume resistivity there are many detailed rules and recommendations provided by European IEC 60093 Standard [6] and in some wise comparable American ASTM D 257-91 [7].

Measurements should provide reliable and repeatable data, assessing that a specific technology succeeded in transforming the good insulating textile material in a so called dissipative one, the importance of this enterprise being supported by two specific standards of the field, ESD STM 11.11-200 [8] and mainly EN 1149-1:1996, particularly dealing with the measuring methods of the surface resistivity of protective clothing [9].

## 2. LIMITS AND DIFFICULTIES IN ASSESINT DISSIPATIVE EFFICIENCY

For determining the surface resistivity, as a characteristic of a specific material, we have firstly to measure a surface resistance, using a standard approach. A device provides constant voltage between two electrodes and a sensitive ammeter measures the established current. Essentially, we measure a resistance by calculating the ratio between the applied voltage to the chosen test points and the follow-on current, its value being chosen by the specific set-up; while considering the experimental arrangement, the superficial or the bulk resistivity, as material parameters, could be calculated.

It is imperative to understand that, while dealing with thin, quasi-planar samples it is about unworkable to effectively split the current paths settled on the surface from those determined in the “bulk” of the material. A reasonable approach is to consider the total current as a sum, a joint contribution of superficial and interior paths, a composite contribution of both. If we want to gain a reliable result about the insulating properties provided by a specific material, it is prudent to consecutively achieve both measurements (superficial and bulk resistance/resistivity; the most affordable set-up is with three electrodes, one central, the two other interchanging their roles, from active to guard. These active electrodes should be guarded, because the metrological current might be comparable with those currents established in the background. As previously stated, the current paths associated with the surface and volume set-up cannot be completely separated, but function to the electrodes relative position, the determined resistance is on the whole that of a surface, respective of a volume trail. In conclusion, the resulted resistance of insulation is a united result of the surface resistance $R_S$ (determined by considering the current mainly settled in the thin superficial layers, moisture included) and the transverse resistance $R_V$ (mainly determined by the current settled through the "body" of the specimen).

If we aim to compare and characterize the materials by their electrical conductive properties, we need to apply to their resistivity. The resistance depends on the set-up, while the resistivity is the characteristic of a specific material.

The superficial resistivity $\rho_S$ is set out as a potential gradient, with the same direction as the current established along the surface, rated by this current, all connected to the unit. Essentially, the surface resistivity is the ratio between a voltage and resulted current, so it is expressed in the classical unit, Ω. Mainly for explicit separation between resistance and resistivity, the unit Ω is associated the immaterial "square". In other words, the superficial resistivity is numerically equal to the measured surface resistance of that definite material, by using a "square" set-up: the distance end to end of the electrodes is equal with the separation distance between them. This is the "etymologic" justification usage of "Ω/square" unit for surface resistivity.

Additionally, the bulk resistivity $\rho_V$ is the potential gradient (having the same direction as the developed current in the material) divided by the current density. Strictly using the metric system, the unit should be Ω•m. Obviously, it is quite impossible to prepare a cubic model with the dimensions of one meter. More affordable is to deal with the volume resistance between two opposite faces of only 1-cm cube sampled from the tested material; the result will be numerically equal with volume resistivity, expressed in Ω•cm, 100 times greater than the value strictly asserted in International System. A useful presentation upon these complementarities is presented in [10].

Common measurement assumes material resistance above $10^6$ Ω at the usual 100 V DC test voltage [11]. Regarding the surface resistance measurement, the basic principle of is based on putting down specific defined electrodes on a properly selected sample. The electrodes can have circular shape, formed by cylindrical and ring ones [12], [13] or linear electrodes (developing a square configuration), of precisely defined dimensions. For surface resistivity measurements, if the electrodes are put down on the textile face, it assumes all currents flow between electrodes along the surface and do not penetrate into the bulk of the material. It must be also considered the differences when dealing with insulating materials.

## 3. MEASUREMENTS, METHODOLOGY, RESULTS

Dealing with measurements of the surface (or volume) resistivity of poor conductive materials, the main difficulty is generated by the low metrological currents that are "buried" in many other background currents [14].

Wanting to compare the performances and the efficiency of various inserting technologies, we have performed measurements on 19 representative fabric-samples.

We have used the Keithley hard and soft infrastructure, the Electrometer 6517 [15], the shielded chamber 8009 with circular and ring electrodes [16] and the specific High Resistivity Measurement software [17]. Obviously, it was applied the Alternating Voltage method. The metrological current has two polarities, while the background, parasitic ones have only one.

The first difficulty was produced by the voltage that should be applied between the measuring electrodes. No standard frames an optimal or recommended value. Does this parameter have low influence upon the results? During our measurements we encountered different behaviors and we proposed to pick up experimentally sustainable explanations and to furnish affordable explanations, useful for designers and practitioners in the dissipative textile domain.

We must bear in mind that for the 8009 chamber, the multiplication factor for transforming the measured surface resistance in surface resistivity is the dimensionless $17\pi = 53.4$.

The samples having low resistivity (for our domain of interest, about $10^5$ to $10^8$ Ω/square), usually firmly increase the resistance with the applied alternating voltage. In Fig.1 is presented, as representative example, the behavior of a material with insertion of nylon yarn, surface saturated with carbon particles.

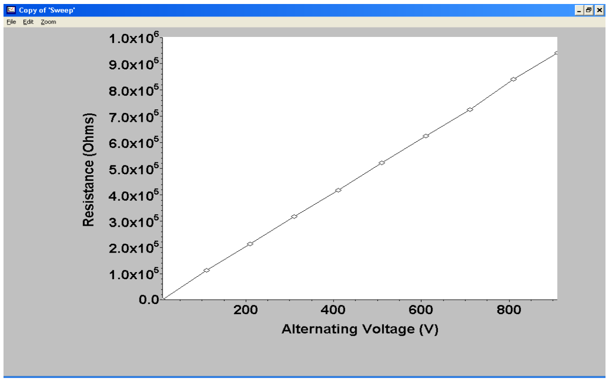

Fig.1. Linear increment of the resistance for a material with insertion of nylon yarn, surface saturated with carbon particles

The explanation is based on higher metrological currents (about mA), comparing with the parasitic ones, also related with the dipole polarization due to the applied electric field.

The low of variation is different for materials having higher resistivity. In Fig.2 is presented a material with the same, incremental trend, as the previous one.

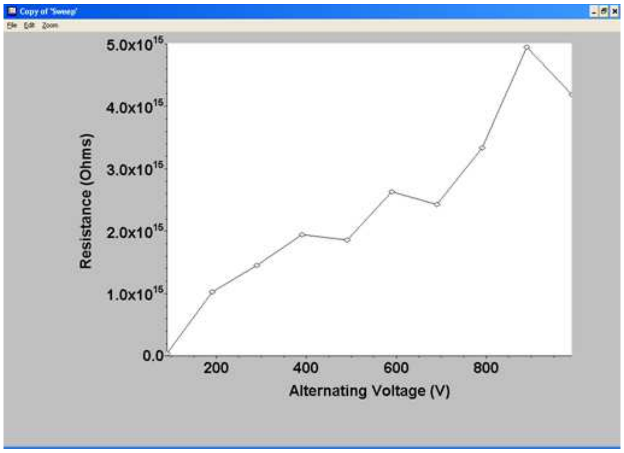

Fig.2. A sample with (inefficient) insertion of 10% stainless fiber and 90% polyester

Unexpectedly, the stainless insertion has low efficiency. We suppose that the technology is ineffective for the surface decay of accumulated charges, due to the isolation provided to the stainless wire by the polyester coating.

A different, decreasing trend was encountered while measuring a sample with insertion of enamel copper (0.25 mm), Fig. 3. As a factor of interest, other samples also having enamel copper as insertion, but with different diameters have not similar rate of decrease.

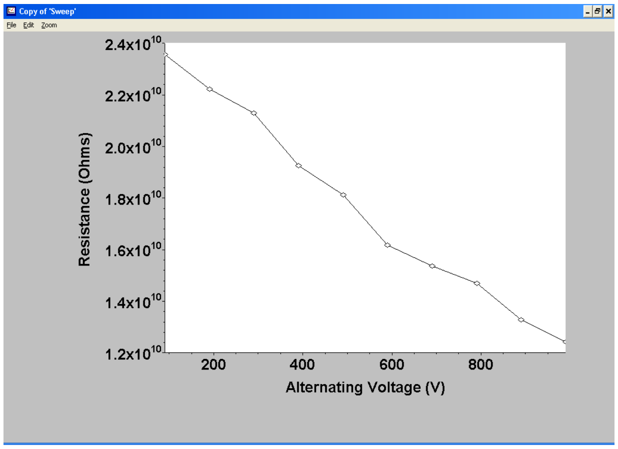

Fig.3. Decreasing trend encountered at a sample with insertions of enamel copper

The explanation of this significant decrease (half of the initial value) might be offered by augmenting of the density of the current paths, determined by the high excitation voltage, up to +/- 990V.

Other type of behavior, a slow decrease of the resistance of a fabric with tinny stainless wire (0.035mm) coated in cotton is presented in Fig.4.

The presumption of insufficient time for conditioning the sample should not be accepted. We have set the measurement system not to deliver any results after the first three cycles. Also the number of voltage bipolar pulses, previously applied to the sample before acquisition is two.

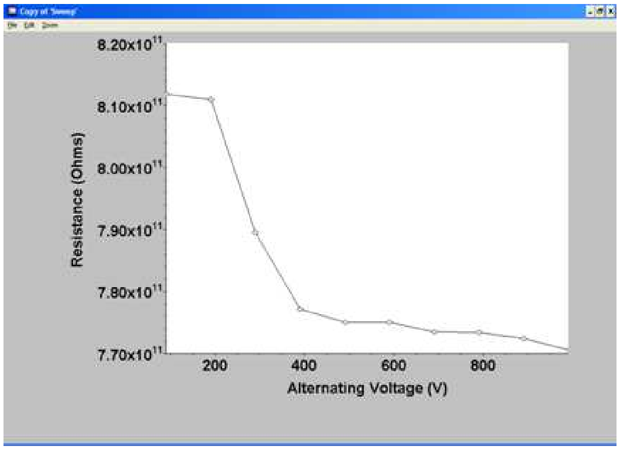

Fig.4. Small decrease (6%) of the resistance for a material at the boundary between dissipative and insulator

Even if the conditioning of the samples was assured by the applied procedure, this slow decrease might be explained by the corresponding polarization of the electric dipoles.

A serious question we had to face was the explanation for some unexpected "failures", as "negative" glitches, leading to unacceptable low values. First of all we had to assess their repetitive or not character.

In Fig. 5 is presented such a situation for a sample with insertion of enamel copper, 0.2 mm diameter.

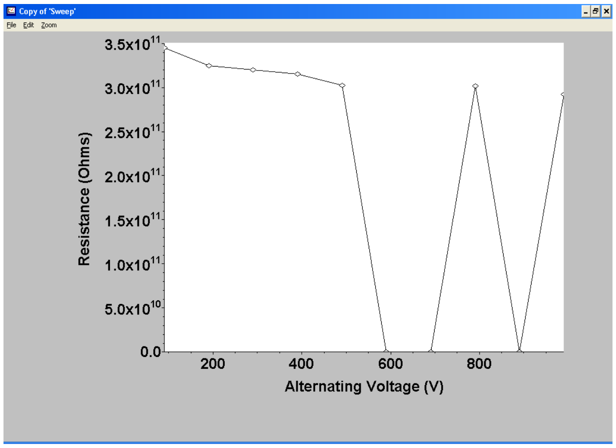

Fig.5. Apparent failures in assessing a sample with enamel copper insertions

These events had quasi-repetitive apparition, they were produced by transients associated with the auto-range option for measuring current. The simplest solution was the manual setting of lowest maximum value of the current that should be measured.

Another category of non-repetitive failures happened only at two types of samples, with insertion of acrylic yarn coated with copper sulphate, Fig.6.

The conductive coating could not be uniformly applied on the acrylic yarn and mainly after a period of usage, involving bending, flexures and frictions. We have noticed that the adherence of copper sulphate was affected.

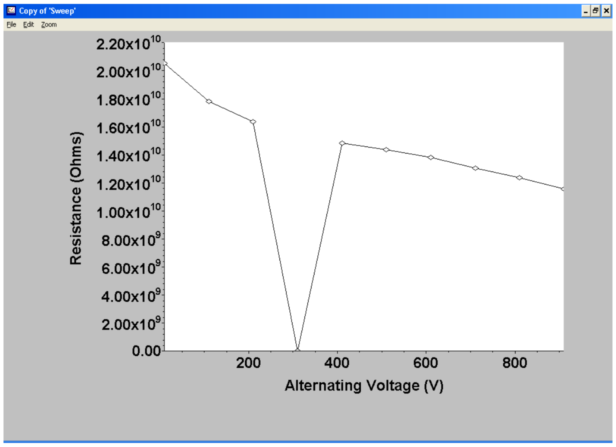

Fig.6. Non-repetitive failure, during resistance measurements on a sample inserted with acrylic yarn, coated with copper sulphate

Conclusively, one possible explanation of these anomalies might be the random establishment of a local higher current that finally interrupt the local low resistance path that acts like an electric fuse.

Wanting to investigate other sources of variability for the lengths for the period of application of the DC excitation voltage, we have measured a fabric specimen with insertion of Ni coated polyester yarn.

In the experiment developed in Fig.7 the duration of every voltage pulse was 15 seconds, so the test was time consuming. A brief calculation leads to the following result: 13 steps, each of them lasting120 seconds (3 cycles for electrification and conditioning and only one for effective measurement) need 1560 seconds=26 minutes.

The second approach, but for exactly the same set-up and specimen to be tested, involved different settings, only 3 seconds the duration of a pulse (6 seconds for a voltage cycle), meaning 9 steps, each of them lasting 24 seconds, a total time budget of only 216 seconds.

We have to note that there are big differences between the measured resistances for the first settlement compared with the second. At 400V excitation voltage, on result is 500 GΩ, while the other is only 300GΩ.

These results prove the very important influence of the duration of intrinsic application of the excitation voltage.

The measured values for these first six figures are synthetically integrated in Table 1.

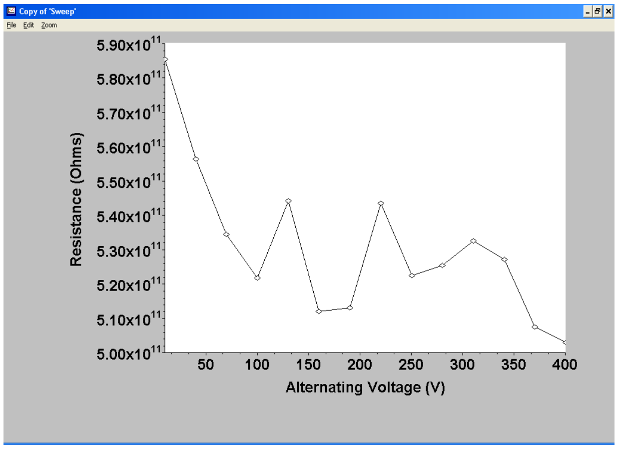

Fig.7.Surface resistance of a specimen with insertion of Ni coated polyester yarn, 15 seconds for every pulse, with 13 steps of 30V

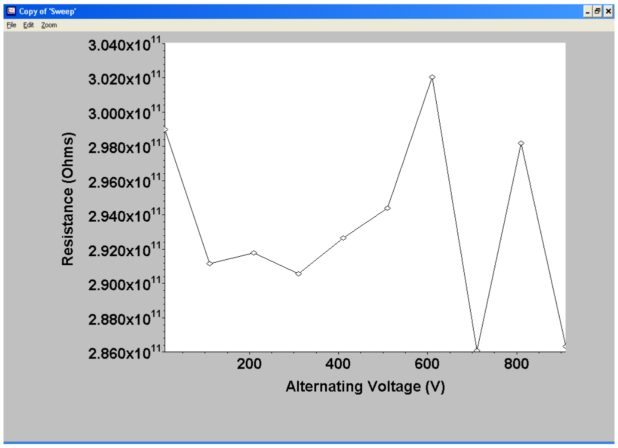

Fig.8.Surface resistance of a specimen with insertion of Ni coated polyester yarn, 3 seconds for every pulse, with 9 steps of 100 V

Table 1 Different influences of the applied voltage on measured surface resistance

| Alternating voltage (+/- V) | 90 | 190 | 290 | 390 | 490 | 590 | 690 | 790 | 890 | 990 | Trend |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S1,Surface resistance, KΩ | 112.1 | 213.5 | 317.2 | 416.8 | 521 | 624.2 | 724.1 | 840.3 | 941.4 | 1035.6 | Firm increasing |
| S2,Surface resistance, TΩ | 311.7 | 1024 | 1452 | 1943 | 1854 | 2628 | 2422 | 3329 | 4942 | 4180 | Unsteady increasing |
| S3,Surface resistance, GΩ | 23.56 | 22.24 | 21.29 | 19.24 | 18.11 | 16.17 | 15.37 | 14.69 | 13.28 | 12.41 | Decreasing |
| S4,Surface resistance, GΩ | 811.7 | 810.9 | 789.5 | 777.1 | 775.2 | 775.1 | 773.4 | 773.3 | 772.4 | 770.6 | Low decreasing |
| S5,Surface resistance, GΩ | 344.6 | 324.4 | 319.4 | 315.2 | 302.2 | F | F | 301.5 | F | 291.9 | Non-repetitive “zero” failures |
| S6,Surface resistance, GΩ | 20.51 | 17.78 | 16.34 | F | 14.81 | 14.34 | 13.82 | 13.06 | 12.37 | 11.55 | Repetitive “zero” failures |

## 4. CONCLUSIONS AND FURTHER DEVELOPMENTS

Even if we have applied the method of “alternating polarity stimulus voltage” while using high-precision electrometer and well shielded resistivity chamber, we have registered, beyond the general accepted “margin” of uncertainty for these type of measurements (+/- 10%), significant dependencies between applied DC voltage and resulted surface resistance.

As a first conclusion: a mandatory requirement aiming to improve the repeatability and reproducibility of our experiments is to specify the +/- DC applied voltage, this essential factor mainly influencing the results.

The same importance also has the duration of the alternating polarities, it is essential to be precisely stated.

An inter-laboratory comparison has sense only by keeping these test conditions. It is advisable to impose the same value, approximate from +/-100 V to +/-200V for the applied voltage. This might be a good compromise between a reasonable value of the established current and the real voltages usually encountered on a clothing dissipative material due to static charges generation.

On the other side, an interval from 3 to maximum 5 seconds for the application of only one polarity is a decent compromise between conditioning (electrification time) and the intrinsic time-budget of our tests.

We have considered for our experiments 19 dissipative textile materials, obtained by 10 different inserting solutions. The relationship between surface resistivity and decay time (the essential parameter in static charge accumulation) is not a linear dependence, due to the strong non-homogenous character of fabrics with conductive insertions.

There were extracted conclusions or just only hypothesis regarding the explanation of different behavior of these dissipative materials, one of the most influencing factors being the (continuous) polarization of electric dipoles in a strong electric field (for the here used experimental set-up could be more than 3kV/cm).

As a further development, we want to finalize a study upon the relationship between the surface resistivity, the volume resistivity and the DC electrical permittivity of the material (a representative parameter indicating the polarization). A complementary approach will be the settlement of the balance of uncertainty and the subsequent methodology evaluating the uncertainty for these high resistance measurements at a good confidence level of 0.95.

## ACKNOWLEDGMENTS

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