A Measuring Procedure to Study the Charge Release Capability of ESD Composite Textiles

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Abstract: The performances of ESD protective garments, made by composite textiles, depend also on the characteristics of such textiles. A tribocharging automated system has been devised and realised to perform tests on samples of such fabrics. Special testing procedures, based on an internal standard and on a suitable definition of Surface Voltage (representing the tribocharge) have been implemented to get structured information about the charge release capability of the relevant textiles.

A model based on the best fitting techniques approach has been selected. The results tests performed on two different composites have been reported and are discussed, so to assess the validity of the approach. Finally, a group of synthetic parameters has been outlined, so allow an easy interpretation of the outcome.

INTRODUCTION

Common fabric clothes are often unsuitable when electronic devices are held by operators during production. Special protective garments, ESD garments made by composite materials, should be used.

The performance of such garments depends also on the charge release capability of the relevant composite textiles. As a testing way suitable to assess such a performance is still under consideration, it is here proposed a special testing procedure.

MATERIALS AND TESTING PROCEDURE

The following composite textiles have been selected:

- SSA10: 65% PES/ 35% cotton + stainless steel grid (10x10 mm)
- SCA10: 60% PES/ 40% cotton + surface conducting grid (10x10 mm)

A 120 mm x 120 mm sample is set into the test cell [1] (see Fig. 1), suspended via 4 nylon threads (pulling force = 50 N). A 5 N vertical force produces a pressure between composite fabric and rotating flat-rod [1]. The PTFE coated flat rod tribocharges the fabric, being driven by a step motor (360° rotations).

As visible in Fig. 2, once the upper surface is charged, an electrode (made by a conducting rubber slab touching the textile and coated by a copper strip) is grounded via a metallic needle contacting the copper strip. In each case, before the tests, the samples are conditioned 48 h into the environmental chamber which hosts the testing set. An "ad hoc" software (supervising the tests and the measurements) controls the testing features (motor speed, number of rotations per test, data acquisition starting time, data sampling rate values and data acquisition times).

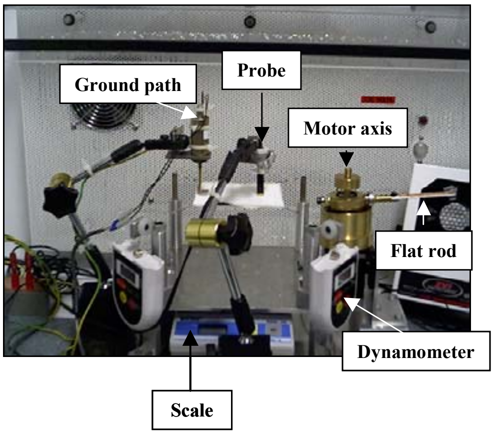

Fig. 1: A view of the test cell

Fig. 2: Electrode grounded by a needle

The measuring probe was set over a swept area, where tribo-charge was formed. It pointed vertically either over the center of the 10 mm square, or over a grid cross.

Each sample experienced 3 separate "center" acquisitions and 3 separate "cross" acquisitions, so to check the repeatability of results. These procedures were repeated for each investigated composite textile at the two selected relative humidity (rh%) values of 50%±3 and 12%±3. After each measuring cycle, the data were suitably post-processed.

A BEST FITTING APPROACH AIMED AT OBTAINING A PHENOMENOLOGICAL MODEL

The above described measuring procedure provided a data output for each run, sample and conditioning. Such an output carried a meaning dependent on the behaviour of each sample/conditioning. The information contained in the charge (surface voltage) decay vs. time plots has been evidenced implementing best fitting techniques, (sum of several exponential terms). An example is reported here below:

$$V(t)=\sum_{i=1}^{k} V_i(t)\cdot e^{-\frac{t}{\tau_i}} \qquad (1)$$

where V_i are the weights and τ_i are the time constants. The performed analysis often evidenced k max = 3. The best fitting techniques can offer 1, 2 or 3 time constants, obtained optimising R^2 (> 0.99).

Here the “sum of exponential terms” assumption, although linked to the charge decay speed on the fabric surface, has basically a mathematical significance and aims to a phenomenological model.

RESULTS

Data obtained at 50% r.h. conditions

The following tables report a summary of the best fitting techniques output regarding tests carried out at 50% r.h.

Table 1: Weight and time constant of the SSA textile, 50% r.h

SSA10	V_1	V_2	V_3	τ_1	τ_2	τ_3
center 1	1030	-	-	0.018		-
center 2	1018	-	-	0.02	-	-
center 3	1045	-	-	0.018	-	-
cross 1	1045	-	-	0.016	-	-
cross 2	972	-	-	0.017	-	-
cross 3	840	-	-	0.016	-	-

Table 2: Weight and time constant of the SCA textile, 50% r.h

SCA10	V_1	V_2	V_3	τ_1	τ_2	τ_3
center 1	1392	-	-	0.015	-	-
center 2	1368	-	-	0.016	-	-
center 3	1320	-	-	0.016	-	-
cross 1	1344	-	-	0.015	-	-
cross 2	1341	-	-	0.015	-	-
cross 3	1473	-	-	0.015	-	-

The behaviour of each textile can be summarised computing just the following three synthetic parameters: $V_{t=0}$=V(0)=initial value, $(dV/dt)_{t=0}$ initial derivative and $V_{t=2}$ = V(2) = value after 2 s.

The latter approach is suitable for quick responses but contains less information than the above tables.

For instance, the fabrics which initially offer a low V(0) and a high d/dt (SV) value would qualify for lowering the probability of an ESD event. On the contrary a textile characterised by a high V(0) and/or by a low initial derivative offers a higher probability for an ESD event. Besides, a fabric showing V(2) slightly lower than V(0) would identify a high charge retention textile.

Table 3: synthetic parameters values for the SSA10, 50% rh

SSA10	$V_{t=0}$	$V_{t=2s}$	$(dV/dt)_{t=0}$
center 1	1030	0	57231.67
center 2	1018	0	56555.56
center 3	1045	0	59725.14
cross 1	963	0	60179.38
cross 2	972	0	57155.88
cross 3	840	0	52514.38

Table 4: synthetic parameters values for the SCA10, 50% rh

SCA10	$V_{t=0}$	$V_{t=2s}$	$(dV/dt)_{t=0}$
center 1	1392	0	92789.33
center 2	1368	0	85482.50
center 3	1320	0	82472.50
cross 1	1344	0	89587.33
cross 2	1341	0	89391.33
cross 3	1473	0	98221.33

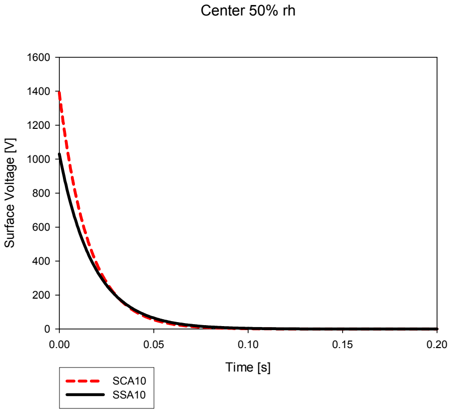

Fig. 3: SV vs. time plot, center, 50% r.h. conditions

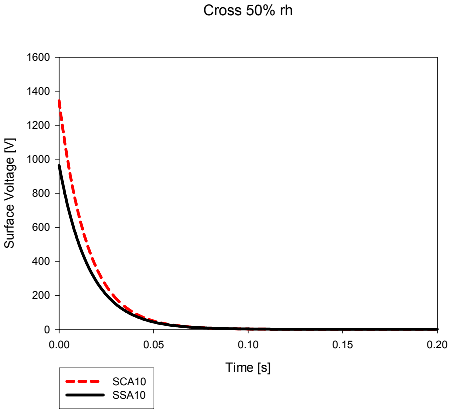

Fig. 4: SV vs. time plot, cross, 50% r.h. conditions

In the tables 3 and 4 are reported the synthetic Parameters values for the SSA10 and SCA10 textiles.

The relevant plots regarding both *center* readings at 50% r.h. conditions and *cross* readings at 50% r.h. conditions are reported in Fig. 3 and 4.

Comments to 50% r.h. test results

Tables 1 and 2 evidence that both SSA10 and SCA10 materials are modelled by a single time constant.

The SV(t) plots of the *center* type data show that in each textile the long term charge retention mechanism is not active: in all cases the V(2) parameter is practically null. Besides, the SCA10 textile shows the highest initial derivative value as well as the highest V(0) parameter. Therefore, comparing SCA10 and SSA10 textiles, it is evident that the SCA10 lends itself to a higher probability for a ESD event.

A second group of comments regards the *cross* probe readings. The above data output show that, in general, the initial SV *cross* values are slightly lower than the *center* values. The initial rate of charge release deserve a note: the *cross* readings are high and practically equal to the *center* readings. The latter finding is consistent with an important flow of charge carriers (from the fabric to the conducting grid) due to the effects of "high" humidity, irrespectively of the mechanisms acting at the interfaces between conductive threads and insulating fabric.

12% r.h. test results.

The following tables report the outcome of tests run at 12% r.h.. A graphic comparison between the tested textiles is shown in Fig. 5 (SV for a single square *center*), and in Fig. 6 as to the SV recorded at the *cross*.

Comments to the outcome of 12% r.h. test results

The Tables 5 and 6 data evidence that SSA10 and SCA10 materials (*center* and *cross*) are modelled by three time constants. The *center* data for the SSA10, and for the SCA10 are examined.

Table 5: Weight and time constant of the SSA textile, 12% r.h

SSA10	V_1	V_2	V_3	τ_1	τ_2	τ_3
center 1	368	480	193	0.04	3.03	29.36
center 2	403	512	189	0.03	2.44	27.44
center 3	634	513	190	0.03	2.75	30.68
cross 1	932	120	147	0.02	2.55	48.82
cross 2	897	124	151	0.02	3.02	47.21
cross 3	765	78	78	0.02	3.00	64.54

Table 6: Weight and time constant of the SCA textile, 12% r.h

SCA10	V_1	V_2	V_3	τ_1	τ_2	τ_3
center 1	1051	449	208	0.03	0.74	9.25
center 2	1103	462	199	0.03	0.75	9.57
center 3	1320	403	177	0.03	0.66	8.29
cross 1	1484	120	126	0.02	0.89	8.77
cross 2	1406	120	129	0.02	0.92	9.35
cross 3	1539	124	123	0.02	0.96	10.19

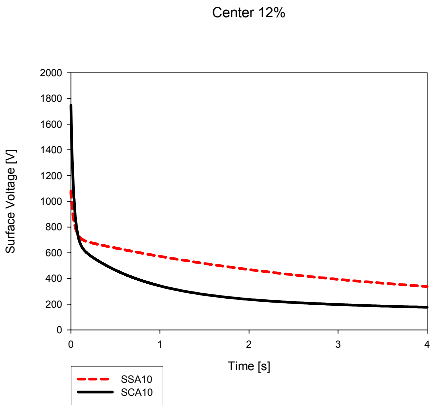

Fig. 5: Comparison between SV plots , center 12% r.h.

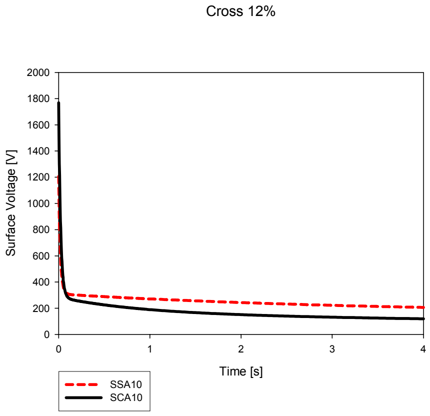

Fig. 6: Comparison between SV plots , cross 12% r.h.

Table 7: synthetic parameters values for the SSA10, 12% rh

SSA10	$V_{t=0}$	$V_{t=2s}$	$(dV/dt)_{t=0}$
center 1	1041	469	10260.18
center 2	1103	446	12642.17
center 3	1337	475	19780.25
cross 1	1199	234	48756.33
cross 2	1172	233	47762.84
cross 3	920	145	45365.10

An important SCA10 decrease of charge is shown and would evidence a trend to a quick release of the tribo-charge. The obtained results deserve a particular comment: during the initial instants, the tested SCA10 textile appears more "dangerous" than SSA10, as the probability that an ESD event takes place is concerned.

During the subsequent times, the SSA10 materials appear more "dangerous"; i.e. the ESD event probability is higher than the one in the other textile case.

Table 8: synthetic parameters values for the SCA10, 12% rh

SCA10	$V_{t=0}$	$V_{t=2s}$	$(dV/dt)_{t=0}$
center 1	1708	237	33753.72
center 2	1764	238	34749.70
center 3	1900	198	43353.39
cross 1	1730	151	69405.03
cross 2	1655	157	66419.56
cross 3	1785	155	71793.71

Besides, the 12% r.h. data output and the reported plots show that, in general, the initial SV *cross* values are higher than the *center* values. The latter assertion is even more valid for the initial values of dV/dt.

The latter finding is consistent with a facilitated flow of charges in the regions around the "conductive grid threads": the probe, for the *cross* readings, is "viewing" surface events dominated by the interfaces between conductive threads and insulating fabric. The data show clearly a higher SV time-derivative for *cross* situations than for *center* situations.

Besides, at dry conditions, the initial charge release (linked to the dV/dt derivative) is different for the tested materials, depending on the interface area (*cross* or *center* readings).

Final comments

The V(2) values (from the sum of exponentials model) evidence, consistently with field experience, a dominating effect of the r.h. on the long term SV decrease for both tested textiles. Then, comparing *center* and *cross* SV values, the V(2) values of dry tests offer a note: in both such cases the cross values are lower than center values. A possible interpretation of the latter data implies that initial high field (non-linear) phenomena exist near the conductive threads. That interpretation agrees with the fact that the field near such threads, at 12% r.h., is less shielded by water dipoles than at 50% r.h. As to the outcome of the "cross" tests, both textiles data evidence that, in the first instants after grounding a grid, phenomena involving a quick moving of the charge (near the conductive threads) are taking place. They would not depend on the presence/absence of humidity, rather they would depend just on the interfaces between threads and fabric. Besides, the "center" tests data would evidence a role of the fabric inside the "squares" during the initial surface charge decrease.

A last comment regards both tested materials: the here measured data, compared to the data published in [3], would evidence that a 10 ns, 1 A peak value HBM discharge is roughly equivalent to a 10 nC charge transfer. In our cases about 1000 V surface voltage was measured: for a 10 pF, offering a 10 nC charge transfer. The charge measured in this work is not a the charge of a partial discharge (PD) rather it is the tribocharge running to ground. In case it reached a chip, this charge would be little dangerous: it would be linked to 10E-6 A max values.

In our cases the earlier the tribo-carge leaves the sample, the less would be the probability of having a ESD/PD event. However he whole data output shows that at dry conditions, these textiles, if rubbed, would keep the surface charge for a relatively long time.

The latter situation (it is common experience that the surface charge, in a cotton/polyester mix, is driven by the r.h. values), would increase the probability that an ESD event happens. However, in case an ESD event (i.e. if a PD event) did happen, then the resistance along the current path should be high, in order to limit the RI^2 dissipation within the chip.

In the end, two different needs are evident: on one hand we should deal with textiles having conductive grids with low resistance threads, on the another hand we should have grids with high resistance threads.

CONCLUSIONS

A new automatic testing procedure has been experimented. A set of "three synthetic parameters" to illustrate the composite textiles behaviour has been advanced. The tested set-up and procedure do correctly affect the smallest time constants and the parameters regarding the first derivative terms. So that the proposed testing approach can represent a tool useful to a designer when studying an ESD protection system including an ESD protective garment, worn by an operator. A comparison, for two significant textiles, between obtained data acquired, at 50% r.h. and at 12% r.h., considering both *center* and *cross* types of measuring the Surface Voltage after tribo-charging offered some information about the main charge release mechanisms.

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