NEW APPROACHES FOR TESTING MATERIALS

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Abstract:

Materials can be assessed for risks from static electricity by measurement of 'charge decay' and by measurement of 'capacitance loading'. This paper describes appropriate experimental methods for these measurements and reports the results of studies on a variety of materials in various test conditions.

1. INTRODUCTION

Many of the risks and problems from static electricity arise in practical use in relation to the voltages that arise on materials when these are charged by rubbing. The influence of surface charge on items nearby relates both to the times voltages are present on surfaces (in relation to the opportunity for static discharges) and to the local electric fields that can arise (in relation to induced charge effects). Assessment as to whether particular materials will, or will not, give rise to risks or problems hence depends not directly on the density of charge retained on the surface, but on the influence of this charge. These points must be taken into account in methods of measurement to assess materials for retained static charge. Other requirements and test methods may be needed where it is necessary to drain charge from a conductor in contact with a material (such as a person standing on flooring), where there is risk that spark discharges may ignite flammable gases (incendivity) or where there is need to protect devices and assemblies against nearby electric field transients (shielding).

To avoid damage to microelectronic devices it has been considered necessary that, in general, voltages on nearby surfaces remain below around 100V. This applies for both conducting and insulating surfaces. For some microelectronic devices (notably magnetoresistive disc drive heads) it is considered that voltages must remain particulaly low – below perhaps 10-20V [1].

The voltage that may arise at the point where a surface is rubbed may be controlled either by enabling the separated charge to dissipate very quickly over the material or by presenting it with a sufficiently large capacitance that only low surface voltages will arise. Recent studies have shown that quite high transient surface voltages can occur at rubbing of common materials (up to 1100V) even with decay times as short as 0.2s [2,3]. These studies also showed that if surface charge experiences a high capacitance, then surface voltages will be limited to very low values. This applies even if quite large quantities of charge are transferred and even if decay times are long. On the basis of this experimental experience it has been proposed [3] that where retained static electricity may present risks, materials may be judged acceptable a) if the decay time is suitably short, and/or b) if the capacitance loading is sufficiently high. It is suggested that a convenient way to combine these two criteria into a single 'Figure of Merit' is to divide the decay time value by the capacitance loading value. This may look like a 'resistivity', but it must be recognised that what is important is what charge on the surface experiences, NOT what can be measured by electrodes in contact.

2. STUDIES

Results of experimental studies have been reported on the charge decay and capacitance loading characteristics of a variety of materials under a variety of test conditions with tribocharging and corona charging [2,3]. These studies involved modest test areas: a 200mm diameter stretched disc for the tribocharging studies and about 45x54mm for the corona charging studies. With orientation towards predicting the performance of full size cleanroom garments from smaller sample measurements, this work is now being extended to larger area samples ($1m^2$) and to full size basic and inhabited garments. The experimental approaches used and the results achieved are described in this paper.

3. METHODS OF MEASUREMENT

3.1 Tribocharging

Experimental studies have been made with tribocharging and corona charging a variety of materials. In these studies measurement are made of the initial peak voltages generated on the surface, the charge transferred to the surface and the charge decay characteristics.

Tribocharging studies have involved, as illustrated in Figure 1, 'scuffing' the centre region of a 200mm diameter stretched area of sample with an initially charge-neutral Teflon rod and observing the electric field at a nearby fast response fieldmeter (model JCI 140) during and after impact [3]. Earthy surfaces are kept well away from the reverse side of the sample.

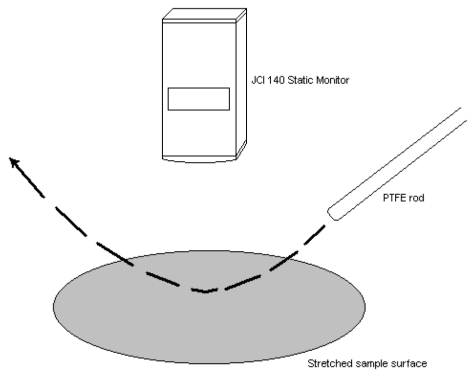

Figure 1: Scuff charging arrangement

The charge transferred to the sample is measured from the charge on the Teflon rod using a Faraday Pail (model JCI 148). The influence of the surface charge with the fieldmeter at 100 mm does not depend on the area of the charge. The fieldmeter reading (as equivalent surface voltage, V) observed for charge held on an isolated conducting disc (supported by small section charge neutral insulation) in the plane of the material is 140 per pC. The capacitance loading is then calculated as:

$$CL = 140 * \text{charge(nC)} / (\text{reading (V)}).$$

The sensitivity of the fieldmeter to the local surface voltage on the material depends on the area charged. Measurements with small conducting discs in place of the material show that if the area charged is assumed to be a patch say 20 mm diameter then the local surface voltage is 11 times the value that would be derived from the normal interpretation of the fieldmeter readings. The local voltage V_l for a 20 mm diameter area of charge is hence:

$$V_l = 1540 * \text{charge(nC)} / (CL).$$

Charge decay times are measured as the time from V_{pk} to V_{pk}/e.

3.2 Corona charging

Studies with corona charging have involved use of a commercial charge decay test instrument (model JCI 155). The basic arrangement is illustrated in Figure 2. A short pulse of corona discharge (20 ms) is arranged to put a patch of charge on the sample surface and a fast response fieldmeter is used to observe the decay of surface voltage after the corona discharge electrodes have been moved quickly away [4].

The charge received by the sample is measured in a special sample support arrangement (model JCI 176) as a combination of the charge linked laterally to the sample support plates and the charge retained where it is deposited and sensed by an induction electrode beneath the open backed sample [3]. Earthy surfaces are usually kept away from the reverse side of the sample, but there is the option to make measurements with an 'earthed backing'. By using a simple dissipative sample material (such as paper or cling film with a decay time of many seconds) it is observed that the initial signal is just an induction charge signal, Q_I, and that as this moves out it becomes just a conduction charge signal Q_c. By finding the factor, f_1, that matches the fall of induction signal to the rise of the conduction signal the total charge Q_{tot} can be calculated as

$$Q_{tot} = Q_c + f_1 * Q_i$$

The factor f_1 depends on the capacitance coupling of the induction electrode to the deposited charge relative to the capacitance presented by the fieldmeter and instrument structure. A value of 2 was aimed for, and a value of 2.33 measured for the actual instrument arrangement.

Capacitance loading can be calculated most simply by comparing measurements with the test material to those for a very thin layer of dielectric, such as cling film. This assumes that similar distributions of charge will be deposited. The capacitance loading is calculated as:

$$CL = \text{charge (nC)} / (\text{initial peak surface voltage} * f_2).$$

The factor f_2 is the 'capacitance loading' calculated for the case of the thin dielectric layer, such as cling film.

The voltage 'reading' shown on the charge decay test unit (model JCI 155) relates to a uniform surface voltage over the whole test aperture. For a 20mm patch of charge the local surface voltage is about 1.6x the voltage value indicated.

Charge decay times are measured as the time from V_{pk} to V_{pk}/e. Experience has shown that such times are little affected by the level of the initial peak voltage [5]. Measurement between two selected voltage levels is strongly affected by the usual non-exponential form of charge decay curves. Charge 'decay time' measurement to 1/e is a convenient figure for simple comparison between materials, but hides possibly relevant behaviour shown in the full decay curves.

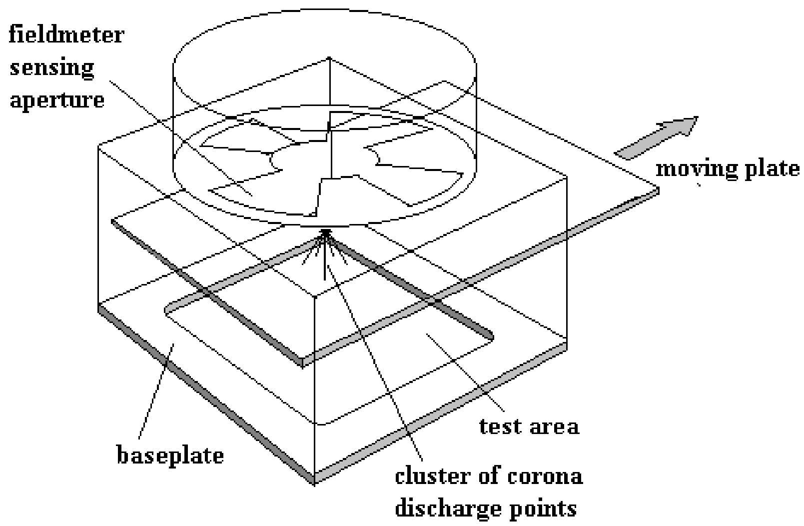

Figure 2: Corona charge decay test arrangement

3.3 Materials studied

a) 'Simple' materials:

polyethylene bag
paper
cotton handkerchief
lingerie fabric
pale blue simple polyester fabric

b) Fabrics with conductive threads:

polyester cleanroom garment fabrics:

2.5 mm	grid	core conductor	with & without antistat
5 mm	grid	core conductor	with & without antistat

c) Special materials used in British Textile Technology Group (BTTG) studies:

PPC 8	100% polyester - surface conductor 20 mm stripe
PPC 11	65/34% poly/cotton 1% core conductor 8x10 mm grid
PPC 12	65/34% poly/cotton 1% St St conductor blended
PPC 17	100% cotton flame retardant (FR) finish
PPC 20	100% aramid
PPC 24	97/3% aramid/core conductor
PPC 27	polyester with flame retardant and antistat finish
XP1	black conductive plastic bag
XP2	A4 transparent plastic document wallet

4. RESULTS

4.1 Initial peak voltage versus decay time

A short charge decay time is a recommended way to avoid problems and risks from static electricity. A decay time below ½ s has been considered adequately short. Fig 3 shows the results of some studies with scuff charging a number of simple materials. If the initial peak fieldmeter readings are interpreted as local surface voltages for an initial patch of charge 20 mm diameter then these measurements show local transient voltages can be as high as 1100 V even with decay times as short as 0.2 s.

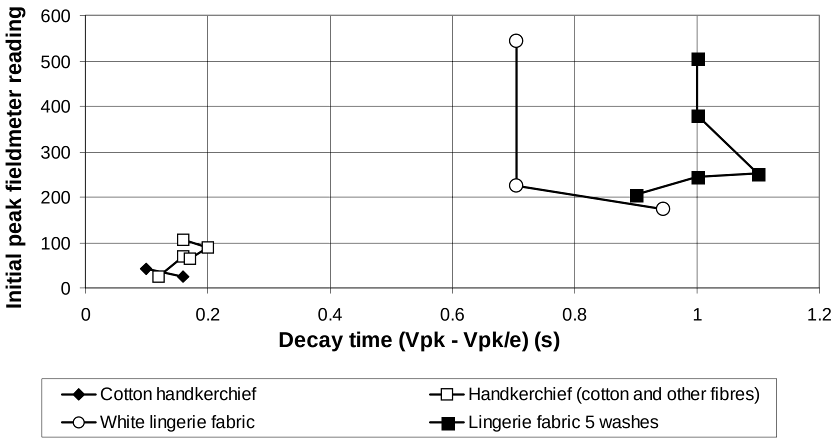

Fig. 3. Variation of initial peak fieldmeter reading with decay time

4.2) Capacitance loading with tribocharging simple fabric

Some results of scuff charging studies on a variety of 'simple' materials at 60-68%RH are shown in Fig. 4. It is noted a) that for these 'simple' materials capacitance loading values seem fairly independent of the quantity of charge, and b) that capacitance loading values range from about 5 (polyethylene bag film) to around 50 (cotton handkerchief).

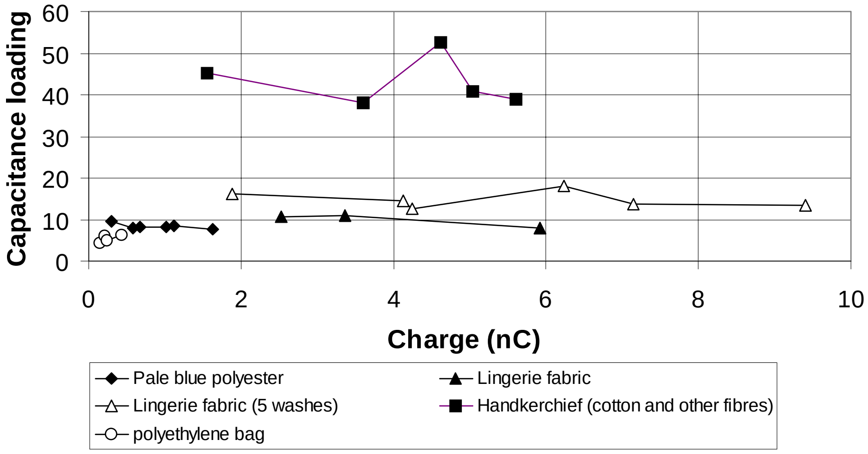

Fig. 4. Variation of capacitance loading with quantity of charge for simple fabrics

4.3 Studies with corona charging

A number of studies have been reported on the variations of charge decay times and capacitance loading with quantity of corona charge transferred to the sample surface [2,3]. At quantities of charge up to 10 to 100 nC many materials showed fairly steady capacitance loading values. At higher quantities of charge, to over 1000 nC, it was noted that some cleanroom garment fabric materials, that include conductive threads, give capacitance loading values that come to increase about in proportion to the quantity of charge. This means that at high quantities of charge the initial peak surface potential of such materials has reached a plateau. In general decay times tend not to depend much on the quantity of charge.

The results of studies on the effect of humidity on the decay time and capacitance loading values of paper, cotton and cleanroom garment fabrics with 2.5 and 5 mm grid spacing conductive threads are shown in Fig. 5 to 8.

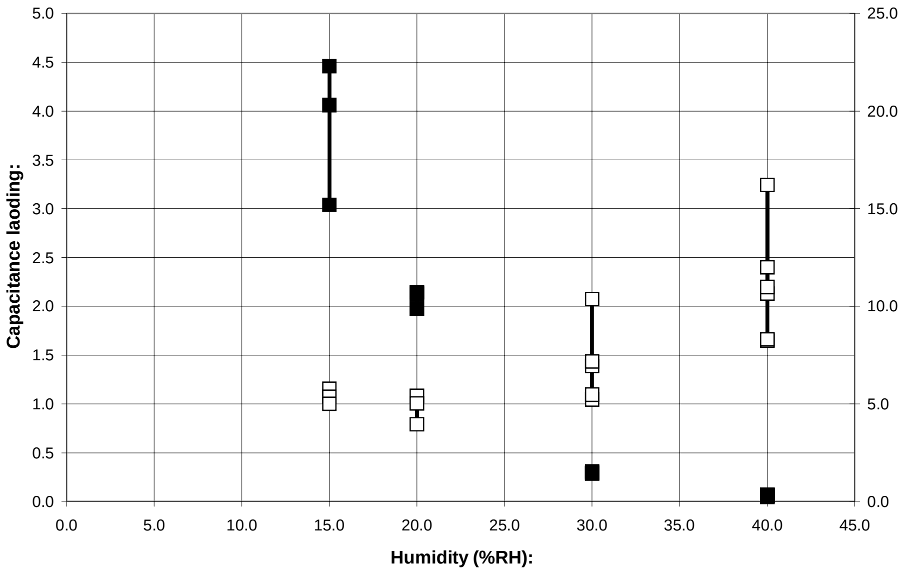

Fig. 5. Cotton handkerchief (*Full points:* decay time *Open points:* capacitance loading)

The measurements for a cotton handkerchief (Fig 5) show that as humidity increases charge decay times decrease greatly and the capacitance loading shows a modest increase above about

20% RH. With a copying paper (Fig. 6) charge decay times decrease to a modest extent but capacitance loading increases greatly. With this paper it may be that the great increase in capacitance loading nearly compensates for an increase in charge mobility, so keeping the change in decay time modest.

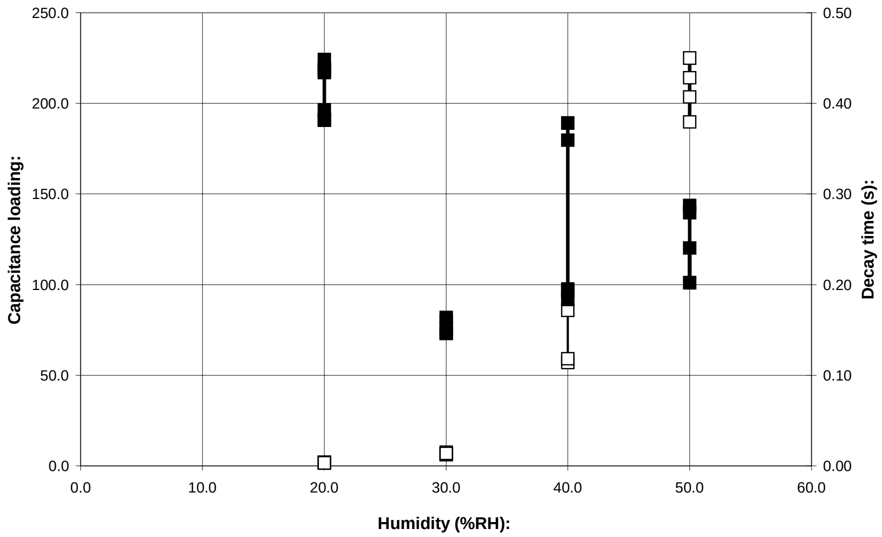

Fig. 6: Copying paper (*Full points:* decay time *Open points:* capacitance loading)

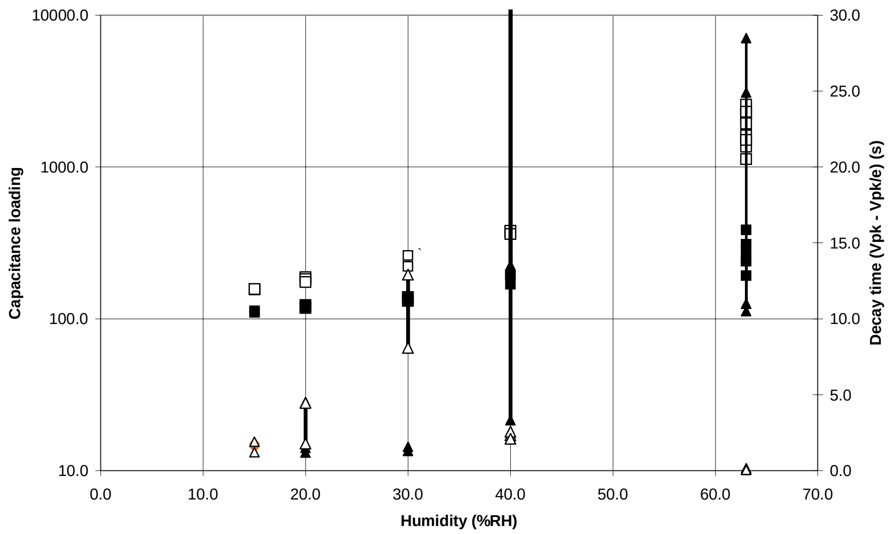

Fig. 7: Polyester cleanroom fabric with 5 mm grid of core conductive threads
(*Full points:* no antistat treatment. *Open points:* with antistat treatment
Square points: capacitance loading *Triangle points:* decay time)

The capacitance loading measurements with the polyester cleanroom garment fabrics that include grids of conductive threads (Fig 7 and 8) show that values:

a) are higher with an antistat treatment than without
b) increase with humidity, and more strongly with an antistat treatment
c) are higher with the smaller grid spacing at low humidities

The charge decay time measurements (also in Fig 7 and 8) show that at low humidity charge decay times can be longer with an antistat treatment than without. At more normal humidity decay times are much shorter with a treatment than without. The turnabout seems to start around 30% RH.

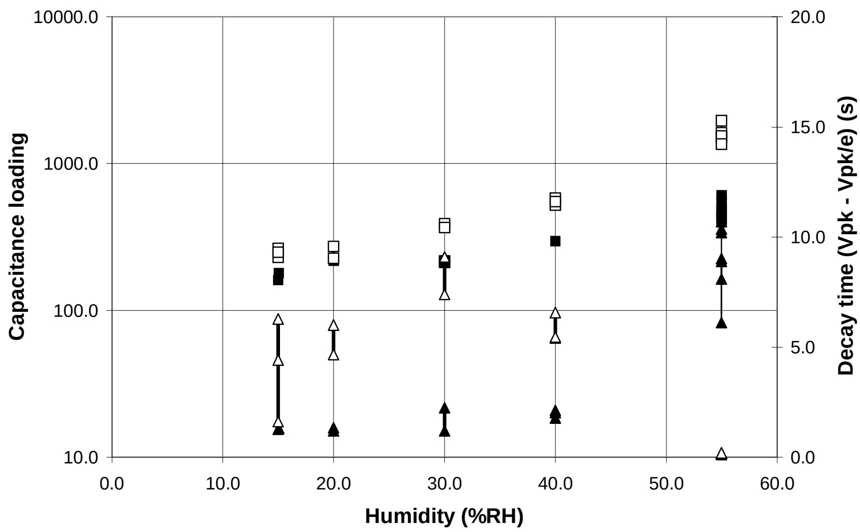

Fig. 8: Polyester cleanroom fabric with 2.5 mm grid of core conductive threads
(*Full points:* no antistat treatment *Open points:* with antistat treatment
Square points: capacitance loading *Triangle points:* decay time)

4.4 Comparison between tribocharging and corona charging

The results of some studies comparing the behaviour of materials as observed with tribo and corona charging are shown in Table 1.

Table 1: Comparison of tribocharging and corona charging studies at BTTG Jan 1999. (23 C 25%RH)

Sample:	Tribocharging performance features:			Corona performance features:	
	Initial Peak reading:	*Decay time (s):*	*Capacitance loading*	*Decay time (s):*	*Capacitance loading*
PPC8	10	3-4	25-84	2	112
PPC11	12	7-8	25-37	4.5	37
PPC12	14	3-5.5	25-35	2.7	97-345
PPC17	350	0.65	3-3.5	0.3-0.35	4-11
PPC20	300	300-600	12-16	270-320	
PPC24	12	7-13	42-50	3.4-3.8	75
PPC27	2		115	0.64	2600-3000
XP1	3		220		
XP2	200	0.7-4	2.7-2.9	0.5	5-7

	Lowest peak volts:	Shortest time:	Loading	Shortest time:	Loading
Best:	PPC27, XP1	PPC17	PPC27, XP1	PPC17	PPC27
	PPC8	XP2	PPC24	XP2, PPC27	PPC12
	PPC11, PPC24	PPC8, PPC12	PPC8	PPC8	PPC8
	PPC12	PPC11	PPC11, PPC12	PPC12	PPC24
	XP2	PPC24	PPC17, XP2	PPC24	PPC11
Worst:	PPC20, PPC17	PPC20	PPC20	PPC11 PPC20	PPC17, XP2

The following points are noted from these studies:

a) the ranking orders for charge decay time and capacitance loading performance are very similar for the two methods of test
b) the values of decay times and the values for capacitance loading are generally comparable (although higher values for capacitance loading are often observed with corona charging)
c) the lowest initial peak surface voltages are associated with the highest values of capacitance loading, as would be expected
d) it seems that high values of capacitance loading may give, or be associated with, long charge decay times

Studies have compared three different electrostatic test methods using the same set of materials as in Table 1 [6]. The first method was that developed at NASA by Gompf [7] involving mechanical rubbing of a stretched disc of material, with an earthed outer boundary, using a PTFE pad. The second method was the modified Shirley Method 18 [8] involving rubbing an isolated stretched disc of material. The third method was the above 'scuff charging' method (referred to as the JCI 'ad hoc' method). Despite the differences in the methods all three gave similar ranking orders in terms of the peak surface voltage generated.

4.5 Larger scale studies

The studies described above have all involved modest sample areas. The aim in using samples of cleanroom garment fabrics is to predict the behaviour expected on full size and inhabited garments. Measurements were carried out with the tester wearing full cleanroom garments of a variety of materials and standing on insulation and out of any earth contact. The tester was connected to a virtual earth charge measurement circuit (model JCI 176). Various areas of each garment as worn were held near the test aperture of a corona charge decay test unit (model JCI 155) - but out of contact with the instrument baseplate. Charge decay and capacitance loading measurements were made on the inhabited garment and, soon after, directly on areas of the garment fabric. It was not easy to stay as still as desirable during the longer of the charge decay times experienced. The measurements showed that generally similar charge decay times applied for the inhabited garments as for modest area samples. Capacitance loading values are comparable between the two sets of measurements. Values tend to be larger for the inhabited garments, probably because the larger than normal distance to the test aperture when standing in the garment reduced the sensitivity to surface voltage values. The studies support the expectation that measurements on samples of fabrics do provide information relevant to the performance of inhabited garments.

5. CONCLUSIONS

The work described shows there are new ways to assess the suitability of materials. The two basic measurements that need to be made are ‘charge decay’ and ‘capacitance loading’. Charge decay time shows how quickly charge created on the surface of a material can migrate away. ‘Capacitance loading’ shows how the surface potential is limited by the nature and structure of the material. It is described as a ‘loading’ as the values are the ratio of the capacitance observed to that for the same distribution of charge on a very thin layer of pure dielectric.

The importance is noted of using appropriate methods for making decay time and capacitance loading measurements. The need is also noted to use instrumentation with adequately fast signal response and data recording. and the demonstration of matching between tribocharging and corona observations.

If the area charged is known, or its actual local surface voltage, then the ‘capacitance loading’ can be expressed as an actual capacitance. It may noted that division of the decay time by the capacitance looks like a ‘resistance’. However, it needs to be noted that charge decay and capacitance loading measurements relate to what charge experiences on the surface - NOT what can be measured by electrodes in contact. It hence seems more appropriate to call this a ‘Figure of Merit’ to avoid confusion with traditional ‘resistance’ measurements.

Values of charge decay times presented have been times from the initial peak voltage to 1/e of this. This a simple basis for comparison between materials. Such time values are rather susceptible to the form of charge decay curves. Decay curves rarely follow an exponential decay curve and t5he rate of decay usually slows up during the progress of charge decay. To ensure materials are considered ‘acceptable’ in terms of their ability to dissipate most of the charge on their surface it is proposed that ‘decay times’ should also be measured as the time from initial peak voltage to 10% of this.

The approaches described do not, of course, answer all aspects of electrostatic risks. They do not cover shielding against electric field transients [7] or the opportunity to draw sparks from materials – these aspects require additional tests. The present methods do, however, provide simple and fair assessment of the suitability of materials to avoid risks from retained electrostatic charge. The corona charge decay approach is shown to give results that satisfy the requirement of matching to behaviour as experienced with tribocharging. Corona charge decay and capacitance loading measurements can be implemented with instrumentation that is compact, portable, quick and easy to use.

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