Measurement of tribo and corona charging features of materials for assessment of risks from static electricity *

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Abstract - Many of the risks from static electricity arise in relation to the maximum surface voltage that may arise when materials are rubbed. The paper describes a new approach for assessing the risks presented by static charge retained on materials by simultaneous measurements of the quantity of charge transferred, the initial peak voltage generated and the rate at which the charge can decay away. The quantity of charge transferred divided by the initial peak voltage is equivalent to a capacitance. If this 'capacitance loading' is large then only low surface voltages will occur with practical quantities of charge transfer, and static problems are unlikely to arise from charge retained on the material itself. This approach provides a necessary addition to assessment of materials by the charge decay time when charge decay times are long.

I. INTRODUCTION

Resistivity measurements have traditionally been the way used to qualify materials where static electricity is thought likely to causes problems or presents risks. In some situations this method of measurement can be appropriate (e.g. flooring and footwear) when the need is to drain charge from a conductor in contact (e.g. from the body to the floor). Where problems arise from static charge retained on a material itself then a measurement of resistivity may be quite inappropriate. Resistivity indicates the fastest route for charge migration, whereas for charge retention it is the slowest route for migration that is relevant. Charge decay measurement is appropriate in such situations. However, it is important that a suitable method is used that is shown to give results that match to the decay of triboelectrically generated charge [1]. It is to be noted that Federal Test Standard 101C does not achieve this [2]. For a material to be acceptable the charge decay time needs to be sufficiently short compared to the time of mechanical actions of charge separation that no significant surface voltage can occur - even as a transient. Decay times below ½s have been suggested as suitable [3].

Fabrics for personal protective clothing and cleanroom garments are usually constructed to include conductive threads. The aim of these threads is to limit the nearby influence of fabric surface charges by proximity to 'earthy' conductors (i.e. to limit surface potential). A low fabric surface potential will avoid risks of damage by direct electrostatic discharge and by indirect induction effects. If the 'conductive threads' have a 'core conductivity' in an insulating sheath there is no sensible opportunity for assessment by resistivity measurement. For cleanroom garments the basic fabric is usually polyester, so charge decay times are likely to be very long - unless the fabric has been treated with an 'antistat' finish. With such materials neither resistivity nor charge decay measurement gives a fair assessment of performance and the ability to avoid risks from surface static charge.

The basic concept of a new approach that has been developed is to measure the initial peak surface voltage created by a known amount of surface charge [4]. This is effectively a 'capacitance loading' of the charge compared to that which would apply for a similar spatial distribution of charge without influence by the material. If one knows the amount of charge likely to arise in particular practical activities then the maximum local surface voltage can be predicted. Assessment of the suitability of materials can then be made either in terms of the charge decay time or the 'capacitance loading'.

The paper describes the experimental studies that have been carried out with tribocharging and corona charging of a variety of materials with simultaneous measurement of the quantity of charge transferred, the initial peak voltage generated and the rate at which the charge decays away.

II. ARRANGEMENTS FOR MEASUREMENTS

A) Arrangements for tribocharging studies

In practical situations electrostatic charge arises on materials by contact or rubbing against other materials. Methods to assess materials need to be based on triboelectric charging or be shown to relate to it.

A simple experimental arrangement has been devised (as shown in Fig. 1) for simultaneous measurement of the charge transferred by rubbing a stretched sample of material, the signal observed by a fieldmeter nearby and of the rate at which this signal decreases as the charge dissipates.

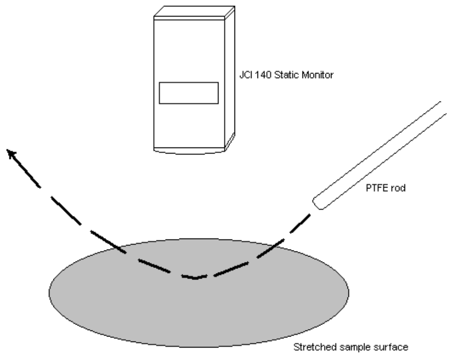

Figure 1: Experimental arrangement for scuff charging materials

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An initially charge neutral PTFE rod is used to 'scuff', wipe or impact the middle of the stretched area of sample material directly under a fieldmeter 100mm above the test surface. The whole of the PTFE rod is charge neutralised before each measurement by, for example, careful proximity to a candle flame. The fieldmeter (JCI 140) readings show a brief initial excursion (usually negative) as the PTFE rod rises from the surface, a polarity reversal to a peak value as the rod is swung quickly away and then a decay as charge migrates away out over the surface of the rubbed material. Fieldmeter readings are recorded either directly into a microcomputer with ¼s time steps or using a Picoscope digital storage oscilloscope. Fieldmeter signals are measured with a resolution better than 1mV (corresponding to 1V of surface potential on a large plane target at 100mm).

The quantity of charge transferred to the surface is measured by inserting the rubbed end of the previously charge neutral PTFE rod into a Faraday Pail (JCI 147). Charge values are measured up to 20nC with a resolution around 10pC. Charge values are recorded manually.

B) Arrangements for corona charging studies

The method for tribocharging measurements described above is simple, but only really suitable for experimental studies. Corona charging provides the basis for an easier to use, more consistent and less operator dependent way to measure the charge decay characteristics of materials [1,3,4]. The corona charging approach uses a high voltage corona discharge to deposit a patch of charge on to the surface to be tested and then uses a fast response electrostatic fieldmeter to measure, without contact, how quickly the surface voltage, developed by this charge, falls as the charge migrates away. The corona discharge points are mounted, as shown in Fig. 2, on a light plate, which is moved quickly away (within 20ms), immediately after corona charge deposition - which is usually of 20ms duration. The charge received by the sample is measured in the sample support arrangements (JCI 176) as a combination of the charge linked laterally to the sample support plates and charge retained where it is deposited and sensed by an induction electrode beneath the open backed sample.

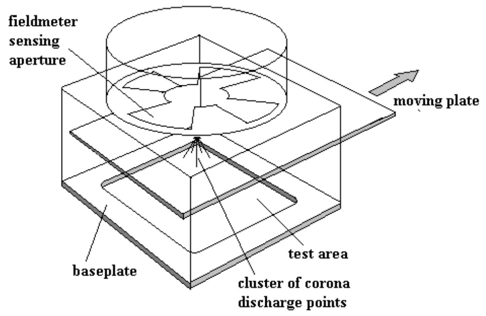

Fig. 2. Arrangement for corona charge decay measurements

The charge measurement method was an enhancement of that used previously [5]. The 'induction' electrode was an approximate geometric match for the sensing region of the charge decay test unit above the sample - so about half the charge retained couples to the induction sensor. This proportion can be established by corona charging, for example, a Melinex film sample and then carefully transferring this to a Faraday Pail for total charge measurement. The charges received by the induction sensor and by the mounting plates are measured by virtual earth charge sensing amplifiers. These measurements are recorded separately on a Picoscope digital oscilloscope and then appropriately combined to give the total charge received. The virtual earth charge amplifiers have built in relaxation time constants of 2s each, so they are effectively self-zeroing between tests.

In each corona charging study measurement is made of the corona charge received by the sample, the initial peak surface voltage and the charge decay characteristics.

C) Interpretation of observations

In the test arrangement used for the 'scuff charging' studies it has been shown that the fieldmeter signals relate to the quantity of charge available to couple to the fieldmeter sensing aperture and do not depend on the charge area if this is small. Isolated charged discs up to 26mm diameter gave a reading of 0.14mV/pC at 100mm.

In the corona charging test arrangement (JCI 155) the sensitivity to charge on a small isolated disc in the plane of the test aperture was measured to vary from about 0.83/pC for very small charges to 0.62/pC at 20mm diameter. A figure of 0.73/pC seemed appropriate for the likely size of the deposited patch of corona charge.

In both cases the 'capacitance loading' was calculated as the signal which would have arisen from the quantity of charge deposited divided by the initial peak fieldmeter signal observed.

Taking a 20mm diameter area for both tribo and corona charging, then actual local surface voltages were about 11x the fieldmeter readings in the tribocharging studies and about 1.6x in the corona charging studies [4].

Charge 'decay time' values quoted are the times from initial peak voltage to 1/e of this value. This is convenient for simple comparison between materials, but hides possibly relevant behaviour shown in the full decay curves.

D) Special materials used in tests at BTTG

PPC 8	100% polyester - surface conductor 20mm stripe
PPC 11	65/34% poly/cot 1% core conductor 8x10mm 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 condutor
PPC 27	polyester with flame retardant and antistat finish
XP1	black conductive plastic bag
XP2	A4 transparent plastic document wallet

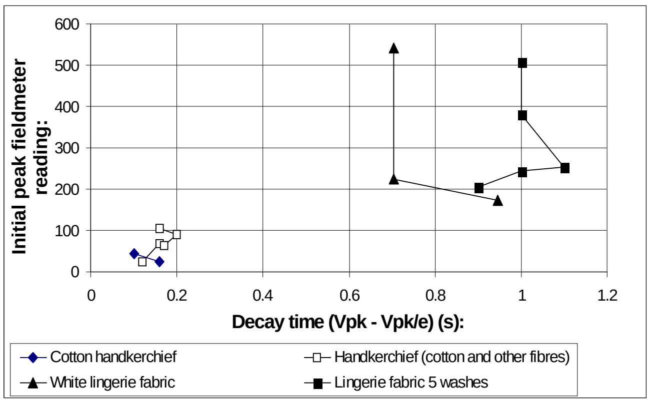

Fig. 3. Variation of initial peak fieldmeter reading afetr tribocharging with charge decay time

III RESULTS

A) Surface voltage versus decay time

The initial peak fieldmeter readings observed after scuff tribocharging a number of simple fabrics are shown in Fig. 3 above. Taking the area charged as being about 20mm diameter then the actual local surface voltages would be about 11x the fieldmeter values.

Rapid dissipation of charge is a way commonly used to control static risks. The present measurements show that quite high local surface voltages can be generated by tribocharging actions even when charge decay times are as short as 0.2s.

B) Capacitance loading with tribocharging simple fabrics

Two main results arose from scuff charging studies on a variety of 'simple' materials at 60-68%RH (examples shown in Fig. 4). First, that the initial peak fieldmeter reading seems to vary in proportion to the quantity of charge transferred, giving a fairly constant value of capacitance loading. Second, that capacitance loading values range from about 5 (polythene bag film) to around 50.

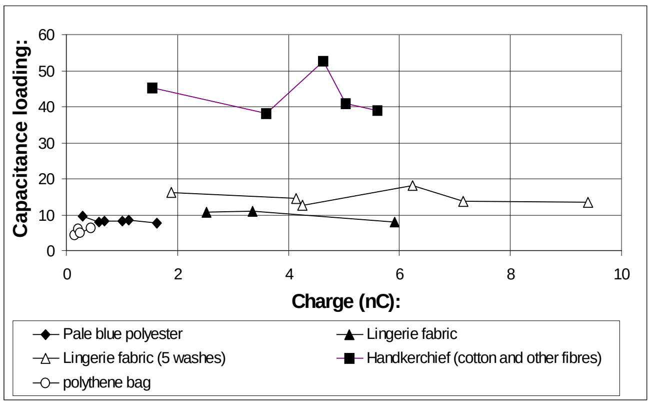

Fig. 4. Capacitance loading for tribocharging simple fabrics

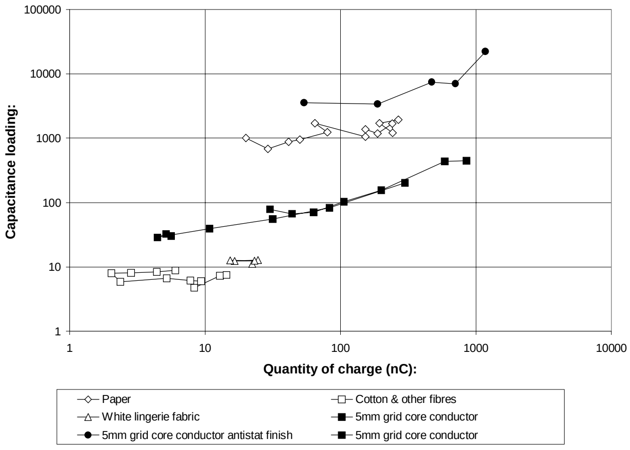

Fig. 5. Variation of capacitance loading corona charging

D) Corona charging measurements

Two main points arose from measurements of capacitance loading with corona charging (some results shown in Fig. 5). First, that with simple materials the 'capacitance loading' values seemed fairly independent of the quantity of charge transferred. This was similar to observations with tribocharging. The capacitance loading of paper is quite high. With fabrics that include conductive threads, the 'capacitance loading' was usually much higher and usually increased with quantity of charge. At low quantities of charge, comparable to those used in the tribocharging studies, the capacitance loading values are generally comparable. At high quantities of charge the loading tends to become proportional to quantity of charge. This means that the readings (and hence initial peak surface voltages) are tending to plateau out at high levels of charge.

E) Corona charging of fabrics including conductive threads

Fig. 6 and 7 show the results of capacitance loading measurements from corona charging studies on a number of polyester fabrics that included core conductive threads. These were fabrics with and without antistat finish for cleanroom garments. Measurements were made at high and low levels of humidity.

Fig. 6 shows that for fabrics from manufacturer A, with threads on a 5mm grid, the capacitance loading with the antistat finish is very dependent on humidity. With no finish humidity has little influence. At high charge levels capacitance loading is roughly proportional to quantity of charge. The fabrics in Fig. 7, from manufacturer B, show less influence by humidity, less influence by the quantity of charge transferred and only a modest increase in capacitance loading between a 5mm and a 2.5mm grid.

Fig. 8 shows the charge decay time values for the fabrics shown in Figs. 6 and 7. All these show long charge decay times except those with an antistat finish at high humidity values. It was also noted that the fabrics without an antistat

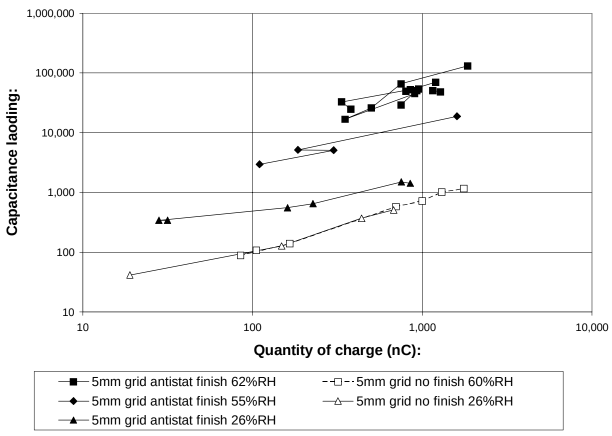

Fig. 6. Variation of capacitance loading with fabric finish and humidity (A)

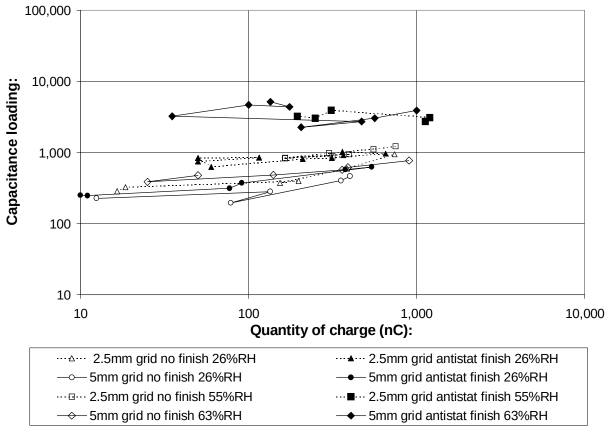

Fig. 7. Variation of capacitance loading with grid spacing, fabric finish and humidity (B)

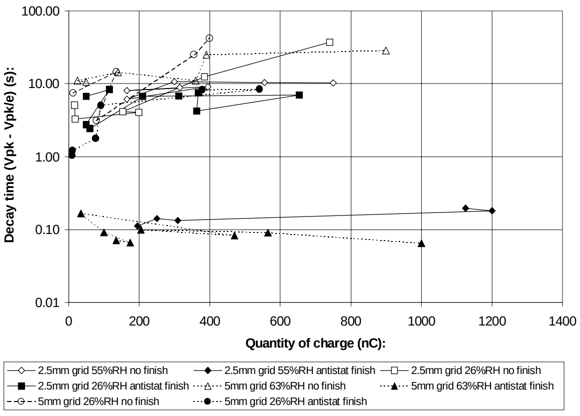

Fig. 8. Variation of charge decay times for fabrics (A) and (B) with and without antistat finish with humidity

finish showed charge decay curves that flattened out after an initial faster decay.

F) Tribo and corona charging comparison

The results of studies carried out under low humidity conditions on a variety of fabrics (listed in D above) with 'scuff' tribocharging and with corona charging are summarised in Table 1. The following points are noted:

a) the ranking orders of 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) high values of capacitance loading tend to give, or be associated with, long charge decay times

Some studies have recently been reported [6] comparing three different electrostatic test methods and using the same set of materials as used above (listed in D). The first method was that developed at NASA by Dr Gompf [7] involving mechanical rubbing with a PTFE pad of a stretched disc of material with an earthed outer boundary. 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. Some differences between the NASA method and 'scuff charging' may have arisen from differences in the time to measure the initial peak voltage when the decay time is short.

It is suggested that the advantage of having direct measurement of the charge transfer associated with individual tribocharging events is that one can make a more meaningful absolute comparison between repeated events on the basis of the capacitance loading values obtained without need for special consistency in the tribocharging arrangements.

Calculation of capacitance loading values provides opportunity to estimate the actual surface voltages likely to arise from charge generation in practical tribocharging situations. From this, realistic assessments may be made of risks.

The special advantage of the corona charging approach is that test equipment and procedures are easy to use by less skilled staff so measurements may be made with confidence in industrial as well as test house situations.

Table 1: Comparison of results from tribocharging and corona charging studies on special fabrics at BTTG (23C 25%RH)

Sample:	Tribocharging performance features:				Corona performance features:	
	Initial Peak reading:	*Decay time (s):*	*Cap loading*		*Decay time (s):*	*Cap 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	PPC17, XP2
					PPC20	

IV. CONCLUSIONS

The present studies have shown that quite high local surface voltages can be generated by tribocharging actions even when charge decay times are as short as 0.2s. A short charge decay time is a way commonly used to avoid problems from retained static charge on materials. Decay time target values in common use and in 'standards' need to be reviewed and probably reduced.

It has been shown that knowledge of the quantity of charge transferred in tribocharging and corona charging studies provides an additional route to charge decay time for reliable assessment of the suitability of materials for use in static sensitive situations. One also now has a way to normalise tribocharging measurements, instead of needing to rely solely on the maximum surface voltage that can be created by enthusiastic rubbing actions. There is thus better opportunity to compare material test results between different operators and different test conditions and arrangements. The opportunity to make equivalent measurements based on corona charging provides the prospect for compact and self contained instrumentation that will enable materials to be assessed easily and quickly and without the need for specially trained skilled staff.

It is proposed that the suitability of materials for avoiding problems from retained charge in static sensitive applications be judged a) by whether the charge decay time is suitably short, and/or b) whether the capacitance loading is sufficiently high. Material acceptance values will depend upon the application - and much lower values are needed for example in MR head manufacture than for ignition of flammable gases. In general, it is suggested that charge decay times should be less than 0.2s and/or the capacitance loading should be greater than about 100.

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