Assessment of the Electrostatic Suitability of Materials

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Abstract: **It appears there is renewed interest in consideration of ways to assess the electrostatic suitability of materials. The present paper comments on a number of existing standard Test Methods and notes some of the features that need to be taken into account for more modern materials and applications. Corona charge decay measurement has been used for many years as a practical and justified approach to the assessment of a wide variety of materials - including fabrics, plastic films, papers, solid surfaces, powders and liquids. Experimental measurements will be shown to illustrate present approaches for corona charge decay assessment. This will include observations on capacitance loading measurement and opportunities to predict very long decay times from modest observation periods.**

Keywords: **charge decay; electrostatic characteristics; electrostatic test methods; measurements; Standards**

I. INTRODUCTION

It appears there is a renewal of interest in the availability of test methods that reliably assess the suitability of materials for both the avoidance of risks and problems and for constructive applications of static electricity. The aim of this paper is to comment on a number of approaches in use for assessing materials, to note basic requirements that need to apply to provide users with information in which they can have confidence and to comment on the corona charge decay method of testing.

II. RELEVANT ELECTROSTATIC FEATURES

The suitability of materials to avoid risks and problems and for the constructive use of static electricity depends on four main features:

1) the voltages that can arise on surfaces (and hence the electric fields that can be created at nearby items) when they are contacted or rubbed by other surfaces

2) the ability of materials to drain charge away from surfaces or conductors in contact with them

3) the ability of materials to provide shielding against electric field transients

4) the ability of a material to support a damaging or incendive electrostatic discharge

The relevance of each of these characteristics depends on the area of application. The first of these, the surface voltage that arises from charge retained on a material itself, is the root cause of most electrostatic problems and of opportunities for applications. It is this that is responsible for attraction of dust and debris, clinging of thin films, shocks, the opportunity for occurrence of incendive discharges and the direct and indirect risks of damage to microelectronic components and the upset of operation of such systems.

The ability of materials to drain charge from conductors in contact is appropriately covered by resistance measurement [1] - for example for footwear and flooring to control body voltage during activities such as walking. Shielding and the support of incendive discharges are separate topics that require their own appropriate methods of measurement [2,3].

III. GENERAL COMMENTS ON STANDARDS

The important thing about a Standard method of assessment is that it should match the requirements of users and in ways that are not specific to a limited number of present day materials but provide capability into the future. Clever application of physics principles are not relevant if measurement results do not, or may not, match to the behaviour that users may experience with materials!

The main aim of this paper is to consider test methods that are appropriate to assess the risks and opportunities presented by the surface voltages that may arise on materials after they have been in contact, have been rubbed together or have been otherwise charged – for example by induction. However, a few comments are appropriate on the other areas noted above.

Standards are well established for assessing the ability of material surfaces to drain charge away from conductors in contact by measurement of resistance [1]. Such measurements are particularly relevant for judging the suitability of flooring and of footwear.

The test method usually referred to for assessing the effectiveness with which materials provide shielding against electric field transients was developed for the microelectronics industry [2]. Its judgments are based on measurement of energy transfer. This may be fine for that particular area of application, but it reveals little about shielding characteristics in other areas where the electric field transients may well involve much lower frequency variations of electric field. A more general method has been described that involves measuring the attenuation of electric field as a function of frequency [4]. This provides practical information down to very low frequencies (for instance 5Hz). This is relevant, for example, to questions of the shielding provided by cleanroom garments that include conductive threads against charges created by body movement with under-garments. A prospectively interesting offshoot from such attenuation measurements is that they also provide opportunity to determine noninvasively the resistivity of inner layers of composite films and of conductive threads within fabrics [5]. This approach may well also have relevance for preliminary assessment of the risks of incendive discharges from charged fabrics [6] (the fourth item above) as an alternative to the adopted Standard approach [3] before gas probe testing [7].

IV. SURFACE VOLTAGES FROM TRIBOCHARGING

The surface voltage that may arise after materials have been in contact or have been rubbed together is a major interest in assessing the suitability of materials to avoid risks from static electricity or the suitability for a variety of applications. Historically the suitability of materials has been assessed by resistivity measurement [1]. This approach is not suitable for many modern materials because they are non-homogeneous and possibly non-linear.

When a surface is contacted or rubbed the charge separated will be fairly uniformly distributed over the contacted area. This charge will migrate most quickly via any low resistivity routes available but will tend to be held stationary on any more insulating areas. The avoidance of risks requires that materials show only low surface voltages after contact or rubbing. This requires that charge on the areas contacted or rubbed can migrate away within timescales comparable to the time of separation of the surfaces to avoid creating significant surface voltages. This means being concerned more with the time of retention of charge on the more insulating areas of a material surface than with the rapid movement of charge over any low resistivity features of the surface. Thus the most appropriate and direct way to assess the suitability of a material is by observation of how quickly charge migrates (dissipates or decays) after a tribocharging action. This method of test is usually referred to as charge decay time measurement.

In many beneficial applications of static electricity it is necessary that the surface voltages, and associated electric fields, remain in place for appreciable times. This capability is, of course, equally well assessed by charge decay time measurement.

V. CHARGE DECAY TIME MEASUREMENT

A number of approaches have been developed and Standards published for the measurement of charge decay time and comments have been published on a number of these charge decay test methods [8]. It was noted that tribocharging is used in very few [9] of the formal test methods. It is difficult to define simple and reliable ways to tribocharge materials consistently and tribocharging can only be used for a limited range of materials. Of other test methods developed it is only corona charge decay for which work been reported to demonstrate that decay behaviour sensibly matches that for the decay following tribocharging [10].

A tribocharging approach was developed to examine the electrostatic suitability of cleanroom garments [11]. These garments are made of fabrics (mainly polyester) that include a pattern of conductive threads with the aim of reducing the surface potentials likely to arise in use. The test method involved local and brief tribocharging of an area of an inhabited garment with measurement of the local surface voltage. Because it is difficult to make consistently repeatable tribocharging actions measurements were also made of the charge transferred at each tribocharging action [11]. Observations of surface voltage were then expressed in terms of volts per unit of charge (V nC^{-1}). What was clear from the results obtained was that the surface voltages observed (per unit of charge) were dominated for these materials by the capacitance experienced by the surface charge to the pattern of conductive threads rather than by the rate of decay – which was quite slow. The maximum surface voltages became progressively lower as the conductive threads became closer spaced. There was little influence on whether the threads were surface conductive (low measured resistivity) or core conductive (extremely high surface resistivity). This work made it clear that the voltage per unit charge observed on materials depended on two factors: how quickly charge decayed relative to the time of separation of the surfaces after contact and also on by how much the surface voltage was supressed by the capacitance experienced by the charge (a factor that has been termed the 'capacitance loading'). This work also showed, very clearly, that measurement of resistivity could not be used as a generally reliable and applicable method to assess the suitability of materials. Although the non-homogeneity of these cleanroom garment fabrics is easily visible, it needs to be recognised that most practical materials are non-homogeneous to some extent – and this cannot easily be recognized. For instance, paper looks homogeneous – but has a very different structure within its treated surfaces [12]!

Thinking of the results of the above studies from a practical point of view it was clear that the characteristics needed to achieve low surface voltages following tribocharging were either a short time for decay of charge or, alternatively, a high capacitance loading combined with a more modest value of decay time [13]. This 'modest' charge decay time is needed to avoid progressive build up of surface voltage by repeated tribocharging actions. In order to use 'volts per unit of charge' results, information is required on the quantities of charge likely to arise in practical local tribocharging actions.

While it is feasible to measure charge decay after tribocharging, and suitable test procedures can be described, care is needed in the selection of appropriate instrumentation and with the experimental set-up and environment to get good consistent results – even with results based on measurements of volts per unit of charge. Tribocharging approaches are hence better suited to specialist laboratory investigations rather than to standardised industrial test laboratory use. A more appropriate and generalised approach for simple and reliable testing of materials is the measurement of charge decay time following corona charging.

The basic arrangement for measurement of corona charge decay is to use a short corona discharge pulse to deposit a local patch of charge on the surface to be tested and to measure the surface voltage created by this charge and how quickly this voltage decays with time. Figure 1 shows a suitable arrangement. A small cluster of corona discharge points is mounted on a light moveable plate. A short duration pulse of high voltage is applied to the discharge points and the plate and discharge points are moved quickly away so an electrostatic fieldmeter mounted just behind the plate can measure the voltage on the test surface [12,14].

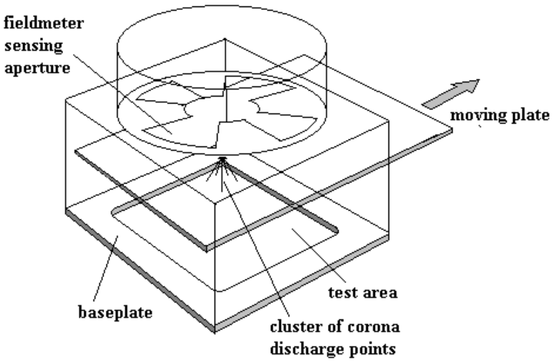

Figure 1: Arrangement for corona charge decay testing

Typically corona voltages are used between 3 and 10kV with durations of 10-20ms and the plate is moved fully away within a time around 20ms.

Figure 2 shows charge decay curves observed on a sample of paper with two different corona voltages. It is to be noted that while the initial peak voltages are very different for the two levels of corona voltage, and the associated very different quantities of charge deposited, the form of the decay curve and the decay times to 1/e and to 10% are very similar for the different levels of voltage at time zero – 100ms after the end of charging.

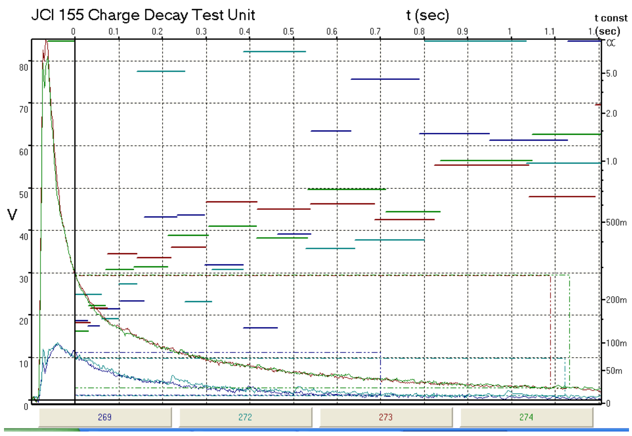

Figure 2: Examples of charge decay on paper. Decay time to 1/e for high initial peak voltage 0.25s and 0.29s for the low voltage.

It will also be noted that the decay curves do not have an exponential form. Hence it is not appropriate to talk of an overall 'decay time constant' - but of the time to achieve a particular fraction of the observed initial surface voltage – and the times to 1/e and to 10% are commonly chosen and appropriate fractions. It will also be noted that the zero of the time axis has been offset. The reason for this is that with tribocharging it takes time for contacting surfaces to separate – typically 100ms for manual tribocharging actions. It is then appropriate to measure decay times from this offset zero rather than from the initial peak of the surface voltage observed.

If the charge deposited on the test surface is measured [13,14] then the effective capacitance experienced by the charge is provided by the value of volts per unit charge. Since different geometries of instrumentation may give different peak voltages per unit of charge (for example due to different spreads of charge with different corona arrangements) it is appropriate to normalise such measurements by comparing them to the voltages observed when charge is deposited on a thin film of a good dielectric [13,14]. This provides a dimensionless parameter that is independent of the particular instrumentation used. This has been called 'Capacitance Loading'.

The relevance of corona charge decay time measurements for assessing the electrostatic suitability of materials depends upon whether the behaviour observed matches that observed with tribocharging. A number of studies have been reported [10,11] that show there is indeed quite good matching. Figure 3 shows one example of charge decay comparing corona and tribocharging behaviour. It will be noted that the time axis of the corona decay observations has been shifted (as noted above) so that both decay curves start with time zero at the point at which the charging action ceased – at the end of corona charge deposition and at separation of contacting surfaces.

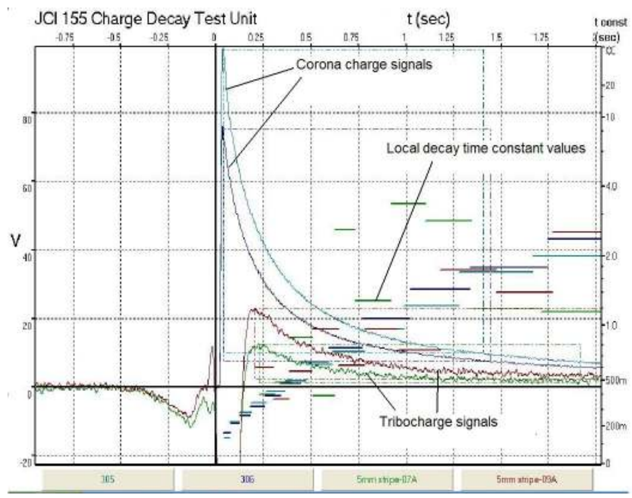

Figure 3: Comparison of charge decay curves for a cleanroom garment fabric with tribocharging and corona charging. Note the time zero is set to be the end of the charging action.

It has been noted that decay curves do not have an exponential form. A useful way to compare decay curves for different materials is to calculate the effective local decay time constant over short intervals during the progress of charge decay. Such calculations are shown in Figure 2. It has been noted, in particular when studying materials with slow charge decay rate, that after an initial settling down period the local decay time constants come to increase linearly with time. This provides opportunity to predict the time for charge decay to reach a selected end point from observations over a much more limited time scale [15]. This can usefully reduce testing time when studying materials with decay times in the range 10^4 to 10^6s.

VI. CONCLUSIONS

This paper has summarized the results of a number of studies that show:

- that measurement of charge decay time and 'capacitance loading' provide information appropriate to assess the electrostatic suitability of materials against tribocharging actions.
- that charge decay time measurement is a more appropriate approach for assessing materials than resistivity measurements. In practice it is the time it takes for charge to dissipate that is needed for judgment of suitability.
- that corona charge decay measurement is a valid, practical and simple way to match the characteristics of materials exhibited after tribocharging.
- that corona charge decay measurements provide the basis for a much fuller understanding of the behavior of materials than just a 'suitable' or 'not suitable' judgment against some set criteria.
- that as corona charge decay measurements can be made on a wide variety of materials (e.g. thin films, fabrics, papers, solid surfaces, powders and liquids) this provides the basis for a widely applicable Standard method of test.

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