TRIBOCHARGING STUDIES ON INHABITED CLEANROOM GARMENTS

J N Chubb John Chubb Instrumentation Ltd, Unit 30, Lansdown Industrial Estate, Gloucester Road, Cheltenham, GL51 8PL, UK (Tel: +44 1242 573347 Fax: +44 1242 251388 email: jchubb@jci.co.uk)

Abstract: Studies are reported on the surface voltages created on inhabited cleanroom garments when these are subject to tribocharging actions. It is shown that the voltage created per unit of charge does not depend on whether the garment fabrics include core conductive threads, giving very high surface resistivity values, or surface conductive threads, which show resistivity values well within the requirements of formal electrostatic Standards. Lower surface voltages per unit of charge are observed for the closer spacing of the conductive threads. These results call into question whether measurement of resistivity is the most appropriate basis for assessing the suitability of materials.

Keywords: tribocharging; assessment of materials; Standards.

1. INTRODUCTION

Standard methods to assess the electrostatic suitability of materials have been based on measurement of surface resistivity [1,2]. The present studies have been concerned with testing how well this approach applies to cleanroom garments.

Cleanroom garments are based on tightly woven fabrics of polyester that include patterns of conductive threads to control the risks from static electricity that can be expected on simple polyester fabrics. It is the surface voltage created by tribocharging actions that presents the major source of risk from static. The main objective of the studies to be described was to examine whether surface voltages created on practical inhabited cleanroom garments related directly to surface resistivity. If it did not, then to see whether they relate to another measurable parameter.

2. TEST METHODS

2.1 Inhabited garments

The surface voltages created on inhabited cleanroom garments have been measured by the test subject standing on an insulated charge measurement support plate and having a region of the upper arm rubbed by a wool surface while the surface voltage is measured by an electrostatic fieldmeter [3,4].
The cleanroom garment is worn over normal clothing with just a shirt covering the arm. To stabilize the position of the upper arm the lower arm is rested on an insulated support. The fieldmeter is mounted from the arm support tripod to maintain a 100mm spacing between the sensing aperture of the fieldmeter (a JCI 140 Static Monitor) and the rubbed area of the sleeve. The physical arrangement is shown in Figure 1.

Tribocharging was achieved using a wooden kitchen spoon covered with a wool sock wrapped round and held in place with an elastic band. This was held by the test operator who was clothed in a cleanroom garment known to provide low surface voltages, and the operator was bonded to earth. The arrangement is shown in Figure 1.

Use of a wool surface on a wooden spoon provided a much simpler test arrangement than the Teflon rod used in previous studies [3,4]. With the Teflon rod it was necessary to charge neutralize it before each test and to swing it well away into an electrostatically shielded region immediately after rubbing the test area to avoid influencing the readings of the fieldmeter. The wool surface on the wooden spoon provided an easy path for charge to dissipate to earth via hand contact with the test operator. This meant that the charging surface was charge neutral just before the test and then had little influence on fieldmeter readings after the rubbing action.

The quantities of charge transferred are likely to depend on the pressure and speed of the rubbing action. With manual operation it is difficult to achieve consistent charging in successive tests or between different testers. It is hence appropriate to measure the quantity of charge transferred at each test and to express the surface voltage observations in terms of the surface voltage per unit of charge transferred – V nC⁻¹. The charge received on the garment was measured using a virtual earth charge measurement circuit (JCI 178 Charge Measurement Unit) connected to the support plate. The test subject stood on the support plate in socks so there would be good connection to the plate surface (see Figure 1).

The signal from the fieldmeter showing surface voltage and the signal from the charge measurement circuit were recorded using an ADC-212 Picoscope linked to a Dell Inspiron 8200 microcomputer running Picoscope software. Observations were recorded in the single shot mode triggered from the rise in the charge measurement signal. A few seconds of pre-test observations were displayed so that readiness for a test could be observed and pre-test ‘zero’ values recorded. An example of a signal record is shown in Figure 2.

The area of fabric on the sleeve charged by the rubbing action is of modest size. It can be expected that the readings and analogue output from the JCI 140 will hence be somewhat less than they would be for the large plane conducting surface that is used for setting up and calibrating JCI 140 instruments [5]. This means that the surface voltage values reported will be
somewhat less than the actual local peak surface voltage. If the area charged was say 100mm
diameter then the actual local voltage would be about twice the reading recorded if that area was
well away from an earthed backing surface and four times the reading if the area rested close
against an earthed surface. In practice something between these can be expected. Some
additional comments on the interpretation of surface voltage readings are presented in Annex 1.

The test procedure was for the test subject in the selected cleanroom garment to stand on the
support plate, to rest the lower arm on the insulated support, to check that separation to the
fieldmeter was close to 100mm and to observe that the fieldmeter surface voltage reading was
suitably low. The charge measurement circuit was then zeroed. When pre-test observations were
suitably stable the upper arm was rubbed by a single swipe of the wool surface on the wooden
spoon which was swung well out of the way. The test subject remained steady on the support
plate and the arm rest so that both the increase in surface voltage and the dissipation of the
charge from the charged area could be recorded. Ten tests were made for each garment so there
was opportunity to have confidence in the averaging and calculation of errors for each set of
tests.

An example of the recorded charge and voltage signals is shown in Figure 2. The sensitivity
for charge was 1.0V of signal per 100nC of charge. For surface voltage the sensitivity was 1mV
of signal per 1V of surface voltage.

2.2 Fabric sample studies

Studies of tribocharging on samples of the various fabrics used for the inhabited cleanroom
garment studies have been made with a strip of the test material about 300x600mm clipped over
the upper arm area of a cotton shirt to simulate the sleeve area of a full cleanroom. The test
procedure was that as established in previous inhabited garment tests [3,4] and as described
above. The test fabric was charged by a single swipe by a woollen sock fitted over a wooden
spoon. The test operator wore a cleanroom garment with a pattern of threads known to
effectively limit surface voltages and was bonded to earth.

The surface voltage of the fabric was measured with a JCI 140 Static Monitor with its
sensing aperture about 100mm from the test surface. The JCI 140 was operated on its 2kV range.
Charge transfer to the test fabric was measured by the charge received by the plate on which the
tester was standing. This was measured with a JCI 178 Charge Measurement Unit operating in
its 200nC range for the on-sleeve studies.

Surface voltage and charge measurements were recorded using a Picoscope 3224 running on
a Dell Inspiron 8200 microcomputer with Picoscope 6 software. A timebase of 2s per division
was used with triggering on the charge signal. Observations were analysed by calculating average values of voltage step per nanocoulomb (V nC\(^{-1}\)).

2.3 ‘Ball dropping’ studies

The inhabited garments studies described above (2.1) are of course directly relevant to the practical use of these garments. However, the standard deviations in the measurements were sometimes quite appreciable. To get more detailed information on the characteristics of the fabrics some measurements have been made by dropping a ball from a preset height (1.25m) onto an inclined surface of an area of fabric sample stretched tight over a 300mm diameter embroidery hoop. The ball was arranged to bounce directly from the fabric surface into a Faraday Pail (JCI 247) so its charge could be measured (JCI 178). The ball was a 25mm diameter plastic knob with a steel M6 steel mounting screw to the centre. The ball was held in its dropping location on a solenoid so it could be dropped at a convenient moment by interrupting the holding current to the solenoid. The ball had been covered with the same woollen sock material as used in the inhabited garment studies so results could be compared. The surface voltage created at the tribocharging impact on the stretched fabric was measured with a JCI 140 Static Monitor supported perpendicular to the centre of the fabric surface and 100mm away from the impact location. An overall view of the set-up is shown in Figure 3.

The signals showing the charge received in the Faraday Pail, via the JCI 178, and the surface voltage of the target fabric surface, from the JCI 140, were recorded using an ADC-212 Picoscope linked to a Dell Inspiron 8200 microcomputer running Picoscope software. The recorded signals were similar to that shown in Figure 2 but, of course, with an opposite polarity step for charge measurement. The sensitivity for charge was 100mV of signal per 1nC of charge. For surface voltage the sensitivity was 1mV of signal per 1V of surface voltage. The surface ‘voltage value’ used from the Picoscope recordings was the mean of any small oscillation at the initial peak of surface voltage directly after charging.

The test procedure was to mount an area of the selected fabric in the embroidery frame and to check that separation to the fieldmeter was close to 100mm. The wool covered ball was positioned to be held on the solenoid, the charge measurement circuit was zeroed and when the fieldmeter surface voltage reading was suitably low the ball was dropped. Five tests were made for each fabric so there was opportunity to have confidence in the averaging and calculation of errors for each set of tests.

The results of measurements were analysed, as for the inhabited garment tests, by calculating average values for the voltage step increase per unit of charge transferred (V nC\(^{-1}\)).
3. MATERIALS TESTED

Samples of cleanroom garments of standard production design were made from fabrics with surface (S) and core (C) conductive threads in grid and stripe patterns at 2.5, 5, 10 and 20mm spacing. The fabrics made up into the garments and the sample areas of fabric tested were without any antistat finish and so were not subject to any additional washing. The 2.5mm grid fabric was washed three times with a standard domestic wash.

The garments made with surface conductive threads (S) had special conductive tape stitched over the seams to ensure the bonding across the seams conformed to standard resistivity requirements [1]. This is not usually done in practice because antistat treatment of the garment provides adequate cross-seam resistive linkage.

The fabrics were supplied by Mick Dyer, of Micotek. The garments were made up to a standard industrial design by Alsico, based in Belgium.

4. ENVIRONMENTAL CONDITIONS

Testing was carried out in normal laboratory conditions with no control of temperature or humidity. This was felt not to be necessary because observations showed the timescale for charge to dissipate over garment surfaces was several tens of seconds, so this would not affect the voltage measurements observed immediately after tribocharging.

5. RESULTS

5.1 Inhabited garments

The results of measurements on the inhabited garments are shown in Table 1 together with values for surface resistivities of the fabric of the garments. Resistivities were measured in both warp and weft directions. It will be noted that with stripe pattern fabrics resistivities are low in the warp direction (along the lines of the conductive threads) and very high in the weft direction (across the thread pattern). Resistivites are essentially symmetrical for grid pattern fabrics.

The results of the inhabited garment tests in Table 1 show the following main points:
- the garments of fabrics with the surface conductive threads show, as expected, very acceptable values of surface resistivity both over the fabric and across seams. The fabrics with core conductive threads show, again as expected, very high values of surface resistivity - well above the level deemed acceptable in existing electrostatic Standards.
- there was little difference in the volts per unit of charge between fabrics with surface
and with core conductive threads of the same pattern and spacing
- the times for charge dissipation on all fabrics was long (several tens of seconds) so the peak surface voltages observed were not affected by charge dissipation
- the surface voltages per unit of charge transferred (V nC^{-1}) were smaller for the fabrics with the smaller thread spacing
- standard deviations in averaging the sets of 10 tests are larger for the larger thread spacing. This probably arises from variations in the lay of the garment against the surface of the arm. This will have a greater influence on observations where the thread spacing is larger and has less capacitance coupling to the area of charge compared to the arm surface.

These findings call into question whether it is appropriate to assess the electrostatic suitability of materials, in particular materials such as cleanroom garment fabrics, just on the basis of resistivity values. It seems necessary to take into account the influence of the capacitance experienced by charge on the garment surface.

5.2 Fabric sample tests

The results of the tests with the areas of fabric over the arm in Table 2 show values of volts per nanocoulomb somewhat larger than those in Table 1 obtained in the inhabited garment studies. It is suggested that this may be due to the smaller area of the sample compared to a full garment so charge coupled by conduction through the threads would experience a smaller capacitance, so a higher voltage per unit of charge.

5.3 Ball dropping tests

The results of the ball dropping tests in Table 3 show values for voltages per nanocoulomb (V nC^{-1}) for a number of the garment fabrics. These results are summarised by the graph in Figure 4. It will be noted that the voltages per unit of charge are somewhat higher than for those measured with the inhabited garments. This is attributed to both the modest area of the fabric as mounted in the embroidery frame and the lower capacitance experienced by the area charged with the open backing situation – compared to the ‘on arm’ test situation.

Table 3 also includes values for the ‘capacitance loading’ derived by comparison between the values of voltage per unit of charge observed with the fabrics and that measured for a small isolated area of charge. The approach is described in Annex 1.

The quantity of the charge transferred was fairly consistent test to test. It seemed to vary a bit with the thread pattern and increased from around 2.5nC for the 2.5 and 5mm spacings to around
3.5nC for the larger thread spacing. This indicates that for a constant impact for charging there is only a modest variation in the quantity of charge transferred with the pattern of the threads.

Table 3 includes the results of measurements of capacitance loading made with a JCI 155v5 Charge Decay Test Unit with corona charging. The values reported were the measured values extrapolated to \( Q = 0 \) – as discussed in Annex 2 [6,7]. The values are comparable to those observed in the ball dropping studies and show the same trend with variation of spacing of the conductive threads.

6. DISCUSSION

The values of voltage per nanocoulomb (V nC\(^{-1}\)) increase with the spacing between the threads in all the studies. The values differ between the test arrangements. Lower values are observed with the inhabited garments than for the samples on the sleeve or in the ball dropping studies. For the studies with samples on the sleeve the values are about twice that for inhabited garments. For the ball dropping studies the ratio increases with the spacing of the threads.

It seems likely that the main factors limiting the surface voltages with the inhabited garments are the area of the garment over which the conductive threads link conductively and capacitively and the influence of the proximity capacitance between the area charged and the body surface below. The areas of the sample fabrics on the sleeve probably had similar capacitance of the charged area to the arm underneath but the area of the fabric was smaller. With the ball dropping studies the area charged was well away from earthy surfaces but the area of fabric charged was comparable to that for the samples of the sleeve.

The quantities of charge that may be separated in practical situations may be up around 50nC. With this quantity of charge it is clear that appreciable levels of surface voltage can arise on cleanroom garment by simple rubbing actions. It is also clear that to limit surface voltages to low levels it is necessary for operators to be provided with cleanroom garments having fabrics with conductive threads on a small spacing.

7. CONCLUSIONS

7.1 The fabrics of cleanroom garments with the surface conductive threads show, as expected, very acceptable values of surface resistivity. The fabrics with core conductive threads show, again as expected, very high values of surface resistivity - well above the level deemed acceptable in existing electrostatic Standards.

7.2 The surface voltages per unit of charge transferred (V nC\(^{-1}\)) were smaller for the fabrics with the smaller thread spacing
7.3 The volts per unit of charge were somewhat less for the garments with the surface conductive threads than with the core conductive threads of the same pattern and spacing.

7.4 The times for charge dissipation on all fabrics was long (several tens of seconds) so the peak surface voltages created by rubbing were not affected by charge dissipation.

7.5 The voltages that may arise on garment surfaces can be quite large for likely practical quantities of charge transfer at rubbing actions. Effective limitation of surface voltage hence requires that the garment fabrics have a small spacing of conductive threads – for instance 5mm or 2.5mm grid patterns.

7.6 These findings call into question whether it is appropriate to assess the electrostatic suitability of materials, in particular materials such as cleanroom garment fabrics, just on the basis of resistivity values. It seems necessary to take into account the influence of the capacitance experienced by charge on the garment surface.

7.7 It is recommended that assessment of the suitability of materials for practical applications should include measurement of the charge dissipation characteristics as well as the capacitance experienced by charge on the surface [7,8].

Acknowledgements: The values of resistivities reported in Table 1 were measured by Paul Holdstock of Holdstock Technical Services

References:


[7] "Test method to assess the electrostatic suitability of materials for retained electrostatic charge"

Document drafted for British Standards GEL101 committee (www.jci.co.uk/cache/JCITestMethod.pdf)

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<th>Surface conductive threads</th>
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Table 3: Results for ball dropping studies and with JCI 155v5 Charge Decay Test Unit

(CL = capacitance loading)

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<th>Surface conductive threads</th>
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Figure 1: Set-up for testing inhabited garments. Test subject standing on charge measurement plate with arm supported on insulated support. Test operator ready to tribocharge area of sleeve directly in front of JCI 140 Static Monitor.
Figure 2: Example of recording of surface voltage and body charge from tribocharging garment sleeve. Garment fabric included core conductive threads in a 20mm stripe pattern.

Surface voltage (blue trace) $1mV = 1V$ surface potential. Charge (red trace) $100mV = 10nC$.

Initial positive excursion of JCI 140 fieldmeter is response to positively charged wool surface moving quickly away from sleeve from in front of the JCI 140 fieldmeter.
Figure 3: Ball dropping test set up showing solenoid for holding the ball, the fabric target surface stretched on an obliquely mounted embroidery frame, the JCI 140 to measure surface voltage and the JCI 247 Faraday Pail
**Figure 4: Summary of results from ball dropping studies**

VARIATION OF VOLTS PER NANOCOULOMB WITH THREAD SPACING

![Graph showing the variation of volts per nanocoulomb with thread spacing.](image)

- ▲ C stripe
- ▼ S stripe
- △ C grid
- □ S grid

Thread spacing (mm) vs. Volts per nC graph.
Annex 1: INTERPRETATION OF SURFACE VOLTAGE READINGS

It is to be noted that the term ‘surface voltage’ is used to describe the readings and signal output of the JCI 140. This instrument is calibrated in terms of the voltage on a large plane conducting surface. With the present measurements the area of charge is modest so the actual local surface voltage in the middle of the charged area will be rather higher than the values quoted.

If the area charged was say 100mm diameter then, as noted in the user manual for the JCI 140, the equivalent surface voltage would be about:
- twice the reading recorded if that area was well away from an earthed backing surface
- four times the reading if the area rested close against an earthed surface.

In practice something between these can be expected.

The readings from the JCI 140 do, however, show the influence of the charge on the target surface at the sensing aperture of the JCI 140. This may be interpreted in two ways: first, the electric field sensitivity of the JCI 140 is about 23V m⁻¹ per mV of output signal (1V of surface voltage reading). So the readings may be thought of in terms of the electric field created at a nearby earthy surface with a cross-section equivalent to around 25mm diameter. Second, the earthed JCI 140 may be thought of as a probe of the local space potential and in this way the readings in volts are comparable to the local space potential created by the charge on the target surface.

The sensitivity of the JCI 140 to a defined quantity of charge at the ball impact point in the absence of any fabric was measured using a 1p coin glued to the end of a 100mm length of 5mm diameter PVC tube mounted on a length of metal rod. A socket was arranged for the metal rod so that the coin could be located in the plane of the stretched test fabric at the impact location. Any charge on the insulating support tube was neutralized by proximity to a candle flame. The coin was rubbed against a piece of PTFE to charge it, it was then placed into the set location in front of the JCI 140 and after taking a reading of the JCI 140 it was put into the Faraday Pail to measure its charge.

The volts per nanocoulomb (V nC⁻¹) observed in the ball dropping measurements, 96.1±1.3V nC⁻¹, provided a reference level to show by how much the surface voltage on the fabrics was suppressed in the different fabrics. This figure may be compared to the value of 140 V nC⁻¹ recorded in earlier experiments [6].
Annex 2: CAPACITANCE LOADING

The timescales for charge dissipation were quite long, several tens of seconds, so it is clear that the surface voltages on the fabrics were not determined by charge decay effects.

The alternative way to appreciate the results is simply in terms of the relative influence at a local earthed surface of a similar size patch of charge on the various fabrics and compared to that also for an isolated patch of charge. The measurements then show the way the influence of charge on the fabric is suppressed by the structure of the fabric. This effect has been termed ‘capacitance loading’ [6,7]. Table 3 includes values for capacitance loading calculated as the volts per nanocoulomb measured with charge on the isolated coin divided by the volts per nanocoulomb measured with each fabric.

\[
CL = \frac{(V \text{ nC}^{-1})_{\text{coin}}}{(V \text{ nC}^{-1})_{\text{fabric}}}
\]

Measurements have been made of the ‘capacitance loading’ values provided with corona charging for a number of the fabrics. The test procedure for these measurements used a JCI 155v5 Charge Decay Test Unit and followed the standard JCI test method [7].

It has been noted [3] that with corona charging the capacitance loading varies linearly with the quantity of charge. It has been found [3,4,6] that the best basis for comparison between corona charging measurements and the performance of inhabited garments is the value of capacitance loading extrapolated to zero charge. It is these values that are reported in Table 3.

The reason for the variation of capacitance loading with quantity of charge is likely to be increase in the charged area as higher corona voltages and durations are used. This will both increase the self-capacitance of the area charged and the capacitance of this charge to nearby earthy surfaces within the JCI 155 Charge Decay Test Unit. The effect may also occur with a thin dielectric layer such as cling film. By extrapolating to zero charge a common basis for comparison is established.