Electrostatic Performance of Gloves in Realistic Use Conditions[1]

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The functional structures of electronic and electromechanical devices continue to shrink. As they do, their ability to withstand the effects of contamination and electrostatic overstress and electrostatic discharge (ESD) diminish as well.

Cleanroom gloves are critical for contamination control and, where ESD sensitive products are being handled, the ESD performance of gloves are equally important. In the first article in this series, the selection criteria for qualifying and controlling clean room gloves was explored.[1] In the second article, the affects of glove washing and use on glove contamination levels was explored in detail.[2] In this, the third article in the series, the ESD performance of gloves and glove liners under realistic use conditions will be explored.

Among the most sensitive devices with respect to ESD are magnetoresistive (MR) and giant magnetoresistive (GMR) heads, solid state lasers, and semiconductor devices with gate widths less than 0.35 μm. These products have design and performance considerations which demand an aggressive and comprehensive ESD Control Program to deal with their high degree of ESD sensitivity.

Walker expressed the need for a comprehensive ESD control program as early as 1983.[3] As an example of the need for a comprehensive ESD program, Hansel [4] pointed out the need for involvement of operating personnel in the complete solution. Other authors have described the need for ground and charge monitoring systems [5, 6], selection of materials for ESD applications [7, 8], selection and management of air ionizers [9, 10], selection of fabrics for construction of clean room garments [11], and even ESD from pressure sensitive adhesives.[12] More recently the need for a comprehensive ESD control program for magnetoresistive heads was described.[13] However, in none of these articles does the issue of selection and performance of gloves with regard to the ESD control system enter into discussion. This is somewhat surprising, considering the way gloves are used in manufacturing: they are an integral element in the generation of charge and transfer of charge to and from products.

The performance of gloves must be considered from the perspective of the entire ESD control system, especially where the static safe work station is located within a clean room. When gloves are used in a clean room application, the type of clean room garment, wrist strap, monitor, footwear and other factors have to be included in the evaluation of the performance of the glove in control of electrostatic discharge. All these components make up the comprehensive ESD control system and must work together to ensure satisfactory performance.

Materials Selection

Selection of glove material for ESD applications is critical. Nitrile is widely recognized as a glove material suitable for use in the manufacture of products with extreme sensitivity to ESD. PVC gloves are also static dissipative, but are made pliable through the incorporation of

[1] This research was sponsored by Ansell Critical Environment Group, August, 1998

plasticizers. The plasticizers also impart static dissipative properties. Unfortunately, these same plasticizers can interfere with the performance of disk lubricants and under extreme conditions can interfere with film adhesion in plated products. This can render them unsuitable for use in contamination sensitive applications. Natural latex, although widely used in high technology manufacturing, has undesirable properties from an ESD standpoint. Attempts have been made to alter the performance of natural latex through topical surface treatments, but these are found to be unacceptable.

Specifying the ESD Performance of a Clean Room Glove

The ESD performance of a clean room glove can be specified using a number of different parameters. Among these are volume and surface resistance, discharge time, residual charge retention and tendency to tribocharge. Volume and surface resistance are classical methods for specifying conductive properties of material. These are often important in selection or qualification of materials for use in the static safe work place. Discharge time is an important parameter, since it is the arrival at a user defined safe voltage level that often determines the material's suitability for use in a given application. Residual or capacitive charge potential is especially important in laminated or composite structures, where the continuous phase material in contact with the external environment can be highly insulative compared with the bulk of the laminate or composite structure.

Of these, the tendency to tribocharge, that is, to acquire and/or impart a charge when rubbed against or separated from a dissimilar material, is by far the most controversial. The repeatability and appropriateness of tribocharge testing is so in question that "no one test currently available can predict general tribocharging properties for a specific material".[14] Since there is no agreed upon standard for tribocharge testing of materials, attempting to specify gloves from the standpoint of tribocharge properties is, at best, a difficult prospect.

This leaves us with the need to test gloves from the standpoint of their resistance, discharge time and residual charge retention. Resistance tests are reliable, as they are based on currently accepted test methods. Discharge time tests are useful in that they are based on generally accepted test methods and reflect the expected performance of materials in their intended application. Residual charge retention tests are based largely on the experience with packaging materials and are appropriate for glove constructed of laminated or composite structures.

Resistance can be measured using a number of different standards. Standards considered particularly appropriate are those of the Electrostatic Overstress Electrostatic Discharge (EOS/ESD) Association [15] or Federal Standards.[16] It is interesting that a direct correlation can be established between resistance and discharge time.

Discharge time performance has become an industry norm in the specification of gloves for use in the manufacture of hard disk drives. Discharge times are measured for an individual holding their hand on a 20 picofarad charged plate. The plate and operator are charged to some starting voltage and the time to discharge to a target voltage is measured. The most generous disk drive discharge requirement is from +/- 1,000 V. to less than +/- 100 volt in under 5 seconds. The most demanding requirements is for discharge from +/- 1,000 volts to less than 10 volts in less than 500 milliseconds.

Glove Use Strategies

Many different strategies for the use of gloves and glove liners influence testing considerations. The choice of glove liners is end-use dependent. Some companies use glove liners as gowning gloves: they wear the glove liner as they put on their clean room garments and discard them in a laundry bin after use, just prior to donning a pair of clean room gloves. Some individuals continue to wear the glove liner and wear a pair of clean room gloves over them to enter the clean room. Industries which require manual dexterity often prefer a half finger glove liner. In most industries, the use of a glove liner while in the clean room is at the choice of the wearer: many individuals will choose to not wear a glove liner.

All of these choices affect the test strategy. Full finger glove liners that are made of insulative material might interfere with the ESD performance of gloves during use. Half finger glove liners made of insulative materials may not interfere with ESD performance of gloves, since the finger tips are in contact with the glove material. Finally, a full finger glove liner made to be static dissipative may afford some advantage over a full finger glove liner made of insulative material.

Purpose of the Study

These tests were designed to determine the effect of glove strategy on discharge time in a practical application. That is, the time to discharge a charged surface using a number of glove and liner combinations were measured. The experimental design considers the selection of material for the glove, the choice of glove liner and examines the issue of glove cleanliness and relative humidity. The goal of the study was to determine the effects of these variables on glove performance in clean room environments, where the wearer will be wearing clean room garments.

Test Conditions

All gloves in this report were conditioned to and tested at 23 ° ± 2 Celsius (72 Fahrenheit +/- 3) and 50 ± 5 % or 12 ± 3 % relative humidity. Gloves were conditioned for a minimum of 48 hours at each of these conditions prior to testing.

Five different gloves considered suitable for use in clean rooms were tested in this study. Three different types of nitrile gloves were tested to study the effect of chlorinating on discharge performance. Gloves tested in this study were:

- Unchlorinated nitrile gloves,
- Inside only chlorinated nitrile gloves,
- Two side chlorinated nitrile gloves
- Polyvinyl chloride (PVC) gloves, and
- Natural latex gloves.

The three sets of nitrile gloves were provided by the Ansell Critical Environment development laboratory in Ohio. The PVC gloves were from Oak Technical Products, based on the report of the distributor. The natural latex glove was the CR100™ glove, based on the report of the distributor.

Four different glove liner conditions were tested with the gloves. These conditions were selected to be representative of those in common practice in high technology manufacture. The glove liner conditions tested were:

- No glove liner,
- Full finger, insulative, Berkshire glove liner,
- Half finger, insulative, Berkshire glove liner, and
- Full finger, X-static ™, static dissipative glove liner.

Glove Status

Gloves were tested in three states:

- Directly out of the original package,
- after deionized (DI) water wash, and
- after recontamination using sodium bicarbonate as a model contaminant. Glove were dusted off prior to test so they were not visibly contaminated.

Test Protocol

Tests were run alternately while wearing a wrist strap or not wearing a wrist strap. The tester stood on a Teflon™ isolation plate during the test. This was to ensure that discharge was limited to through the charge monitor or through the wrist strap. In the case where no wrist strap was worn, discharge was solely through the charge monitor.

The tests were run while to gloved hand was in contact with a NOVX Series 5000 Monitoring System. Data was recorded using the NOVX Data Acquisition Software. This facilitated recovery of discharge times from applied voltages of ± 1,000 V. to targets of ± 100, 50, 20, and 10 V. Because the NOVX instrument has extremely high input impedance in the path to ground through the electrometer, even an insulative material in contact with the 20 picofarad plate will appear to eventually discharge to some voltage. As a consequence, the natural latex gloves, normally considered an excellent insulator, will discharge relatively rapidly under these test conditions.

A minimum of three gloves were tested under each test condition. The procedure was as follows:

- The subject wore the appropriate glove and liner.
- The subject stood on an insulative sheet to ensure preservation of charge.
- A 20 picofarad charged plate monitor was charged to greater than 1200 volts.
- The operator applied their hand to the charged plate. Normal hand pressure was applied.
- The tester discharged using the wrist strap or, in the case where no wrist strap was worn, measured the discharge time through the monitoring system.
- The discharge time from 1000 volts to 100, 50 , 20 and 10 volts were recorded.

ANALYSIS METHODS

The primary objective was to determine which conditions had a dominant influence on discharge time. To this purpose, it is possible to combine similar test conditions (straight out of the package versus water washed versus subsequently recontaminated) or type of glove (three types of nitrile gloves with PVC, since they are all dissipative). This combining of variables allows for a clearer interpretation of the outcome of the tests.

RESULTS

Wearing versus Not Wearing a Wrist Strap

One test variable included was wearing a groundable wrist strap versus not wearing a wrist strap. The comparison of discharge time of each glove when wearing or not wearing a grounded wrist strap is summarized in Table 1. The results in Table 1 are averaged over all glove liners.

Table 1. Discharge time in seconds from 1000 V. to 50 V. for various glove materials as a function of using or not using a wrist strap for gloves fresh out of the bag at 50 % r.h. (averaged over all liner conditions and wash conditions).

Glove	Wrist strap use	Discharge time, msec.
Unchlorinated nitrile	Yes	77
	No	>10,000
Inside chlorinated nitrile	Yes	71
	No	>10,000
Double chlorinated nitrile	Yes	63
	No	>10,000
Polyvinyl chloride	Yes	65
	No	>10,000
Natural Latex	Yes	>10,000
	No	>10,000

In all cases, not wearing a wrist strap interfered with the performance, in terms of discharge time, of the glove and glove liner under test, as shown in Table 1. In addition, natural latex gloves are not capable of discharging to less than 50 volts in less than 10,000 milliseconds (10 seconds), even while grounding through a wrist strap worn by the tester.

For products with extreme ESD sensitivity, such as MR heads, discharge to less than 50 volts will be required. The degradation of discharge performance to less than 50 volts indicates that wearing a wrist strap is mandatory. Since not wearing a wrist strap degrades the performance of all glove and glove liner combinations, the remainder of our discussion will concentrate on tests in which a wrist strap was worn. Thus we eliminate not wearing a wrist strap in all further data.

Effect of Relative Humidity:

Relative humidity in the test environment had no effect on discharge times for the insulative, natural latex glove. Conversely, the effect of relative humidity could be measured for the three types of nitrile gloves and the PVC glove. The affect of relative humidity on discharge time for these four types of dissipative gloves are shown in Table 2. Data are for unwashed gloves straight out of the bag (i.e., DI water wash and recontamination are not included).
Table 2. Effect of relative humidity on discharge times from 1,000 V. to the target voltage, in milliseconds, for static dissipative gloves.

Glove	Relative Humidity, %	100 V.	50 V.	20 V.	10 V.
Unchlorinated nitrile	50	51	71	105	169
	12	55	83	182	394
Inside chlorinated nitrile	50	48	63	92	126
	12	58	87	162	237
Double chlorinated nitrile	50	47	62	90	150
	12	42	56	88	173
PVC	50	35	44	56	65
	12	36	45	58	67

Lower relative humidity tends to increase discharge time for all three types of nitrile gloves, especially for discharge to 20 volts or less. The effect is most pronounced for unchlorinated, less noticeable for inside-only chlorinated and least noticeable for double chlorinated. The effect of reduced relative humidity on PVC is consistent, but very small. In no case does glove type or relative humidity fail to meet even the most demanding requirement: 1000 V. to less than 50 V. in under 500 milliseconds, regardless of relative humidity.

Effect of Glove Liner

Averaging together all gloves and wash conditions, the effect of the choice of glove liner can be seen, as shown in Table 3.

Table 3. Discharge time from 1000 V. to the target voltage, in milliseconds, as a function of glove liner, all static dissipative gloves and all wash conditions combined.

Liner	Relative Humidity, %	100 V.	50 V.	20 V.	10 V.
None	50	51	67	95	126
	12	41	53	75	116
X-static™	50	51	70	110	161
	12	52	76	153	270
½ finger	50	50	67	107	192
	12	48	70	134	259
Full finger	50	79	70	128	202
	12	50	72	130	225

As the target discharge voltage decreases, the discharge time increases. In no case is the average discharge time for a glove/liner combination greater than 300 milliseconds. Clearly all glove/liner combinations will meet even the most demanding disk drive manufacturer's requirement (1000 volts to less than 10 volts in under 500 msec).

It is not surprising that the bare hand inside a glove affords the fastest discharge times. Human skin resistance is typically modeled as a 1000 ohm resistor. This is well below the 10^5 ohm lower limit for dissipative materials. The X-static™ liner performs nearly as well as the bare hand, except for low relative humidity discharge to 20 volts or less. The half finger, insulative glove liner performs well for discharge time to greater than 10 V. but shows a significant increase in discharge time for discharge time to 10 V. At low relative humidity, the half finger glove liner discharge times to 20 volts or less are adversely affected, but not as much as the X-static™ glove liner. The full finger, insulative glove liner performs the worst of all. Interestingly, the full finger, insulative glove liner shows little sensitivity to relative humidity of the test environment.

Effect of Time:

A important observation was made during the 50 % relative humidity tests. The full finger glove liner performance started out poor but improved rapidly with time. It is believed that this was the result of hydration of the liner material by perspiration. The timing of the effect was not measured. All data reported in Table 3 are for a fully equilibrated liner (i.e., stable readings). The time to achieve acceptable discharge performance may be significantly affected by relative humidity in the test environment and more importantly by the degree that a person wearing the glove and liners sweats from the palm. The current tests were conducted by a wearer who sweats relatively heavily compared to the average person, although this should not affect the performance of the wrist strap or the performance of the charge monitoring system.

More careful observations were made at 12 % r.h., where the effect of hydration of the glove liner should be amplified over testing at 50 % r.h. In the 12 % r. h. tests the time for the glove to reach stable discharge time was measured and found to be about 5 minutes. Table 4 shows the effect of immediately testing the glove and liner versus discharge time after 5 minutes for two types of nitrile gloves and two different glove liners.

Table 4. Discharge times from 1000 V. to the target voltages, in milliseconds, immediately after putting on the glove and liner versus after wearing the glove and liner for 5 minutes. (12 % r.h.)

Glove	Liner	100 V.	50 V.	20 V.	10 V.
2 side chlorinated	X-static™	41	55	98	230
	X-static™ + 5 minutes	38	49	68	116
	Full finger	43	57	85	148
	Full finger + 5 minute	42	58	76	105
Inside chlorinated	X-static™	81	134	266	373
	X-static™ + 5 minutes	44	57	81	117
	Full finger	57	84	164	256
	Full finger + 5 minutes	44	60	96	177

Both the X-static™ and the insulative full finger glove liner discharge times are affected by wear time at 12 % relative humidity, especially for discharge times to 20 volts or less. However, in no case is the discharge time slower than required by the most demanding specification in the disk drive industry.

Effect of Chlorinating:

All liner and wash combinations were averaged together for nitrile gloves to determine the affect of chlorinating. The results are summarized in Table 5.

Table 5. Effect of chlorinating on discharge time, in milliseconds, from 1000 V. to the target voltage. (50 % r.h.)

Condition	100 V.	50 V.	20 V.	10 V.
Unchlorinated	56	77	139	222
Inside chlorinated	53	71	103	142
Double chlorinated	46	63	94	135

Of the various test results in this study, these are the most consistent. The more a glove is chlorinated, the better its' performance in discharge time. Again, the effect is small but measurable. The effect is most prominent for discharge times to 20 Volts or less.

Glove and Liner Combination:

Averaging together wash conditions, we can evaluate a glove's ability to discharge to 10 volts. The results are summarized in Table 6.

Table 6. Interaction between glove type and liner type for discharge time from 1000 V. to 10 V., in milliseconds (50 % r.h.)

Glove	Liner			
	None	X-static™	Half finger	Full finger
Nitrile, not chlorinated	145	164	206	372
Nitrile, inside chlorinated	155	108	146	158
Nitrile, fully chlorinated	111	145	150	135
Polyvinyl chloride	66	125	128	142

These data show that chlorinating the glove has an affect on discharge time, but the effect is inconsistent. A nitrile glove which is fully chlorinated inside and out improved discharge time for all glove liners. The full finger glove liner appears to increase discharge times. However, in no case is the discharge time greater than 500 milliseconds.

Wash Condition:

Three conditions were tested for all static dissipative gloves. These were: direct out of the package, after washing in DI water (followed by towel drying) and after light recontamination using sodium bicarbonate. The results are listed in Table 7.

Table 7. Effect of glove treatment (no wash, DI water wash, recontamination) on discharge time from 1000 V. to less than the target voltage, in milliseconds.

Wash Condition	100 V.	50 V.	20 V.	10 V.
Not washed	45	60	86	127
DI washed	44	56	78	102
Recontaminated	62	90	166	276

These results show that a slight improvement in discharge time is afforded by glove washing. The improvement is most noticeable for discharge time to 10 volts.

CONCLUSIONS

Not wearing a wrist strap causes all gloves to fail even the most generous discharge time requirement. Low relative humidity increases the discharge time for the three types of nitrile and the PVC static dissipative gloves. The use of a glove liner tends to increase discharge time. For a full finger glove liner, the effect is time dependent and the increase in discharge time decreases with time, probably due to hydration of the glove liner from hand perspiration. A fully chlorinated nitrile glove discharges more rapidly then a nitrile glove which is chlorinated only on the inside, which in turn discharges more rapidly than an unchlorinated nitrile glove. Glove liner performance does not seem to be significantly affected by choice of glove material, as all discharge times still meet even the most demanding disk drive company requirements. Finally, washing improves the discharge time performance of the gloves slightly. Recontamination degrades the discharge time performance significantly.

References

1. R.W. Welker and P.G. Lehman, “Using contamination nad ESD test to qualify and certify cleanroom gloves”, Micro 17, no. 5 (1999): 47 - 51
2. R.W. Welker, “Controlling particle transfer caused by cleanroom gloves”, Micro 17, no. 8 (1999): 61 - 65
3. R.C. Walker, “Implementing an ESD Control Program”, Microcontamination, Aug/Sept, 1983, pp. 20 - 24
4. G.E. Hansel, “The Role of the Production Operator in Preventing ESD Damage”, Microcontamination, Aug/Sept, 1984, pp. 43 – 46
5. S. Heymann, C. Newberg, N. Verbiest, L. Branst, “Voltage-Detection Systems Help Battle ESD”, EE-Evaluation Engineering, Nov. 1997, pp. S-6 – S-12
6. J.C. Hoigaard, “ESD Test Equipment and Workstation Monitors”, EE-Evaluation Engineering, July, 1998, pp. 58 – 61
7. M. Banks, “Watch those electrons, ESD battle heats up,” Data Storage, July, 1998, pp. 61 – 62
8. S.L. Thompson, “All About ESD Plastics’, EE-Evaluation Engineering, July, 1998, pp. 62-65
9. E. Greig, I. Amador, S.H. Billat and A. Steinman, “Controlling static charge in photolithography areas”, Micro, May 1995, pp. 33 – 38
10. A. Steinman, “How to Select Ionization Systems”, EE-Evaluation Engineering, June, 1998, pp. 62 – 69
11. B.I Rupe, “Electrical Properties of Synthetic Garments with Interwoven Networks of Conductive Filaments”, Microcontamination, May, 1985, pp. 24 – 28
12. R.J. Peirce, and J. Shah, “Potential ESD Hazards from Using Adhesive Tapes”, EE-Evaluation Engineering, Nov. 1996, pp. S-30 – S-31
13. R.W. Welker, “A Comprehensive ESD Control Program for MR Heads,” Asia Pacific Magnetic Recording Conference, Singapore, 29-31 July, 1998.
14. D. Cooper, and R. Linke, “ESD: Another kind of lethal contaminant?” Data Storage, Feb., 1977, p. 49
15. Electrostatic Overstress / Electrostatic Discharge Association Standard S11.11 - 1993
16. FED STD 101C, Method 404