THE EVALUATION OF A RECOMMENDED TEST PROCEDURE FOR QUANTIFYING THE TRIBOELECTRIC CHARGING PROPENSITY OF CONDUCTIVE, DISSIPATIVE AND INSULATIVE FILMS

By

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ABSTRACT

THE EVALUATION OF A RECOMMENDED TEST PROCEDURE FOR QUANTIFYING THE TRIBOELECTRIC CHARGING PROPENSITY OF CONDUCTIVE, DISSIPATIVE AND INSULATIVE FILMS

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This investigation attempted to examine a possible test procedure for quantifying the triboelectric charging tendencies of conductive, dissipative and insulative packaging film materials against various cylinders made of quartz, brass and Teflon. It also looked at the effect of cylinder weight and the effect of angle of release. Its intent was to evaluate these materials by simulating the potential static charge build-up on the electronic products packaged in these materials while in transit or during handling.

The research found that there was not a significant difference between the various film material classifications in the generation of a triboelectric charge. The effect of cylinder type did show a significant effect with Teflon generating the highest negative charge on all film materials. There was a significant effect of cylinder weight with the heavier brass cylinders producing a larger charge on some film materials. The angle of release does show a significant charging effect with the increase in the degree of incline.

This work is dedicated to a group of people who have contributed and sacrificed in so many ways during my entire academic career. To my family, thank you. Their unselfishness and support has provided me the opportunity to obtain my aspirations.

Also, to a person who means more to me than anything. She has shown tremendous amount of patience, and has helped me through the earlier periods of this venture. For without her help, I might not have developed into the person I am today. Thank you for your inspiration H.M.K.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Notation
nC	nanoCoulombs
PTFE	Polytetrafloroethylene (Teflon)
RH	Relative Humidity
ASTM	American Society for Testing and Materials
EIA	Electronic Industries Association
ESD	Electrostatic Discharge
DIP	Dual In-Line Package
RF	Radio Frequency

1.0 INTRODUCTION

In the handling of static sensitive electronic components, there is concern that the packaged component, not just the package material, could accumulate static charges. These static charges can develop during shipment and handling as the component rubs against packaging materials. The static charges can transpire below the human sensitivity level of approximately 4000 volts, which may result into two predominant failure mechanisms, either an immediate failure of the device or a latent failure due to the oxidation of dielectric layers on these valuable components (Fuqua, 1986). The increasing use of insulating materials such as synthetic polymers and a reduction of size of components make these systems continuously more sensitive to electrostatic discharges (Menguy, 1988).

The annual losses of these sensitive electronic components and subassemblies due to electrostatic discharge has been estimated in the billions of dollars (Jones, 1985). Some typical static charge build-ups through everyday operations and the percentage of annual losses on a functional level are reported in Table 1 (Jones, 1985).

Electrostatic charges can be generated either by electromagnetic induction or by the triboelectric effect. In

Table 1. TYPICAL PRIME SOURCES AND ANNUAL STATIC LOSSES

MEANS OF STATIC GENERATION	ELECTROSTATIC VOLTAGES (volts)	
	10 to 20 PERCENT RELATIVE HUMIDITY	65 to 90 PERCENT RELATIVE HUMIDITY
WALKING ACROSS CARPET	35,000	1,500
WALKING OVER VINYL FLOOR	12,000	250
WORKER AT BENCH	6,000	100
VINYL ENVELOPES FOR WORK INSTRUCTIONS	7,000	600
COMMON POLY BAG PICKED UP FROM BENCH	20,000	1,200
WORK CHAIR PADDED WITH POLYURETHANE FOAM	18,000	1,500

FUNCTIONAL LEVEL	LOSS (%)
COMPONENT MANUFACTURING	16 - 22
SUBCONTRACTORS	9 - 15
CONTRACTORS	8 - 14
END USER	27 - 33

some instances, these two phenomena combine to generate Radio Frequency (RF) interference which transmits a traveling electromagnetic field that can induce currents in stationary or moving conductors resulting in possible damage to the components (ADE, 1981).

Electromagnetic induction is produced when an electric or magnetic body is exposed to the influence of the field of force of another body (Dupuis, 1990). A dielectric breakdown occurs in the insulators of semiconductor products when an induced internal electric field exceeds the electric field between the nuclei of an atom and the electrons which bond the atom together. The electrons are so attracted to the electric field that they break loose from their atoms. These freed electrons create a current which can easily burn through an insulator and cause a short circuit in the device (Huntsman, 1982).

The purpose of this study is to evaluate a suggested test method for measuring the triboelectric tendencies of insulative, dissipative, and conductive films. It is the intent of this thesis to evaluate these materials by simulating the potential static charge build-up on the electronic products packaged in these materials while in transit or during handling. The ultimate goal is to accurately measure the electrostatic discharge (ESD) protective properties of packaging materials.

Triboelectric charging occurs when two dissimilar materials are brought into contact with one another and are then separated. This action will change the polarity of the materials by generating a static charge which causes electrons to be stripped from one material making it positive and leaving the other with a surplus of electrons, making it negative. The amount of surface electrification, or charge transfer is expressed by,

$$Q = C * V \tag{1-1}$$

where: Q = charge generated
C = capacitance between the two objects
V = voltage present at any specific instant

The electrical charge generated is measured in Coulombs, where 1 Coulomb = 6.24×10^{18} electrons. In this study, the charge is represented in nanoCoulombs, where 1 nC = 6.24×10^{9} electrons. The magnitude of charge depends upon the types of surfaces involved, the speed of physical movement, and various other parameters displayed in Figure (1). These variables play nearly equal role in the triboelectric process. No one parameter dominates the total process (Fowler, 1988).

Surface Physicals

Tacticity (coefficient of friction)
Smoothness
Topology Viscoelasticity (conformability)

Material Physicals and Chemicals

Morphology (amorphous, crystalline)
Work Function
Energy Level
Fermi Level
Electronegativity (metals)
Purity
Polymer Backbone
Polymer sidegroups
Physical State (gas, liquid, solid)
Molecular Mobility
Temperature

Contact

Time of Contact
Area of Contact
Number of Contacts (repeated contacts)
Type of Contacts
- rubbing
- rolling
- point
- directional (reversal)

Contamination (surface)

Humidity/Water
Material transfer
Surface Reactions
- Oxidation
- Reduction
- Sulfonation
- Fluoridation
- Particulate
- Grease/Oils etc.

Figure 1. PARAMETERS IN THE TRIBOELECTRIFICATION PROCESS

To determine the polarity of materials, a triboelectric series chart is used as shown in Figure (2) (Electronic Industries Association, 1988). The series indicates the likely charge polarities after triboelectric charging. Two of the cylinders used in this study, quartz and Teflon, are at opposite ends of this triboelectric series spectrum. Brass was used as a control since it lies near the middle of the triboelectric series chart.

Current classification of the film materials that are being used in this study are: conductive, dissipative, and insulative (EIA, 1988). According to EIA standards, conductive materials have a surface resistivity of less than 1.0×10^{5} ohms/square. Dissipative materials have a surface resistivity lying between 1.0×10^{5} ohms/square but less than 1.0×10^{12} ohms/square. Insulative materials have a surface resistivity equal to or greater than 1.0×10^{12} ohms/square.

The surface resistivity is the ratio of Direct Current (DC) to the current that passes across the surface of the film material. It is the resistance , measured in ohms, between two opposite sides of a square and is independent of the size of the square or its dimensional units (EIA, 1988).

The physical property of resistivity is the most important attribute in determining resistance to the flow of these

MATERIALS

INCREASINGLY POSITIVE

∧

QUARTZ
GLASS
MICA
HUMAN HAIR
NYLON
WOOL
FUR
LEAD
SILK
ALUMINUM
PAPER
COTTON
STEEL
WOOD
AMBER
SEALING WAX
HARD RUBBER
NICKEL, COPPER
BRASS, SILVER
GOLD, PLATINUM
SULFUR
ACETATE RAYON
POLYESTER
CELLULOID
ORLON ®, SARAN ®
POLYURETHANE
POLYETHYLENE
POLYPROPYLENE
PVC (VINYL)
SILICON
TEFLON ®

∨

INCREASINGLY NEGATIVE

Saran is a registered trademark of Dow Chemical
Orlon and Teflon are a registered trademark of DuPont

Figure 2. TRIBOELECTRIC SERIES

electric charges. Although resistivity determines the rate of charge dissipation and static charge shielding, it theoretically has no relation to tribocharging (Baumgartner, 1987).

Plastic films are typically electric insulators and generate considerable charges in use and during shipment. The plastic films used in packaging of electronic devices need some degree of electrical conductivity in the protection against ESD. In order to achieve this, three common techniques are used in the fabrication of these films; topical coatings, impregnation and use of additives.

A topical coating is a conductive formulation applied to the surface of a plastic film. After being sprayed on or brushed onto the film, the coating becomes the conductive path for dissipating any electrostatic charge away from the component being protected. The static charge will flow through the conductive layer on the outside of the film to ground, instead of flowing through the device surrounded by the film. These coatings can provide various degrees of conductivity, depending upon the requirements of the products (Ryan, 1984).

A second technique for creating conductivity in plastic film is through impregnation of conductive components such as carbon during the manufacturing process. The carbon acts as an electrical conductor, draining away static charge build-up to ground and preventing the electronic component from ESD damage.

The last method is to incorporate additives into the plastic film during the extrusion process. After the film is formed, the additives migrate to the material's surface where it attracts a micro-thin layer of moisture from the surrounding atmosphere and retains it. The moisture layer, not the specific additive, is conductive (Armstrong, 1984).

2.0 EXPERIMENTAL DESIGN

The design of this experiment was proposed by the EIA and recommended to the D-10-13 Committee of the American Society for Testing and Materials. This test method uses the inclined plane to support the material to be tested and is shown in Figure (3). The inclined material is fabricated from aluminum alloy. It consists of a platform to place the package film material to be tested and clevis mount and an angle set rod to permit various degrees of inclination of the platform.

The choice of this particular method is based on work reported by J. R. Huntsman of 3M at the EOS/ESD Symposium, EOS-6, in 1984 on DIP (Dual In-Line Package) tube containers. DIP tubes are containers commonly used for protecting integrated circuits against static discharges, electrostatic fields, and triboelectric generated charges. Huntsman concluded that a possible charge can be produced on these circuits by sliding within the tube. This might cause damage to the devices when being withdrawn from the container and contacting a conductive surface.

The test is performed by allowing a test cylinder to roll down the surface of the sample material and drop into a Faraday cup to measure the charge generated on the cylinder Figure (4). The charge generated on the cylinder is a

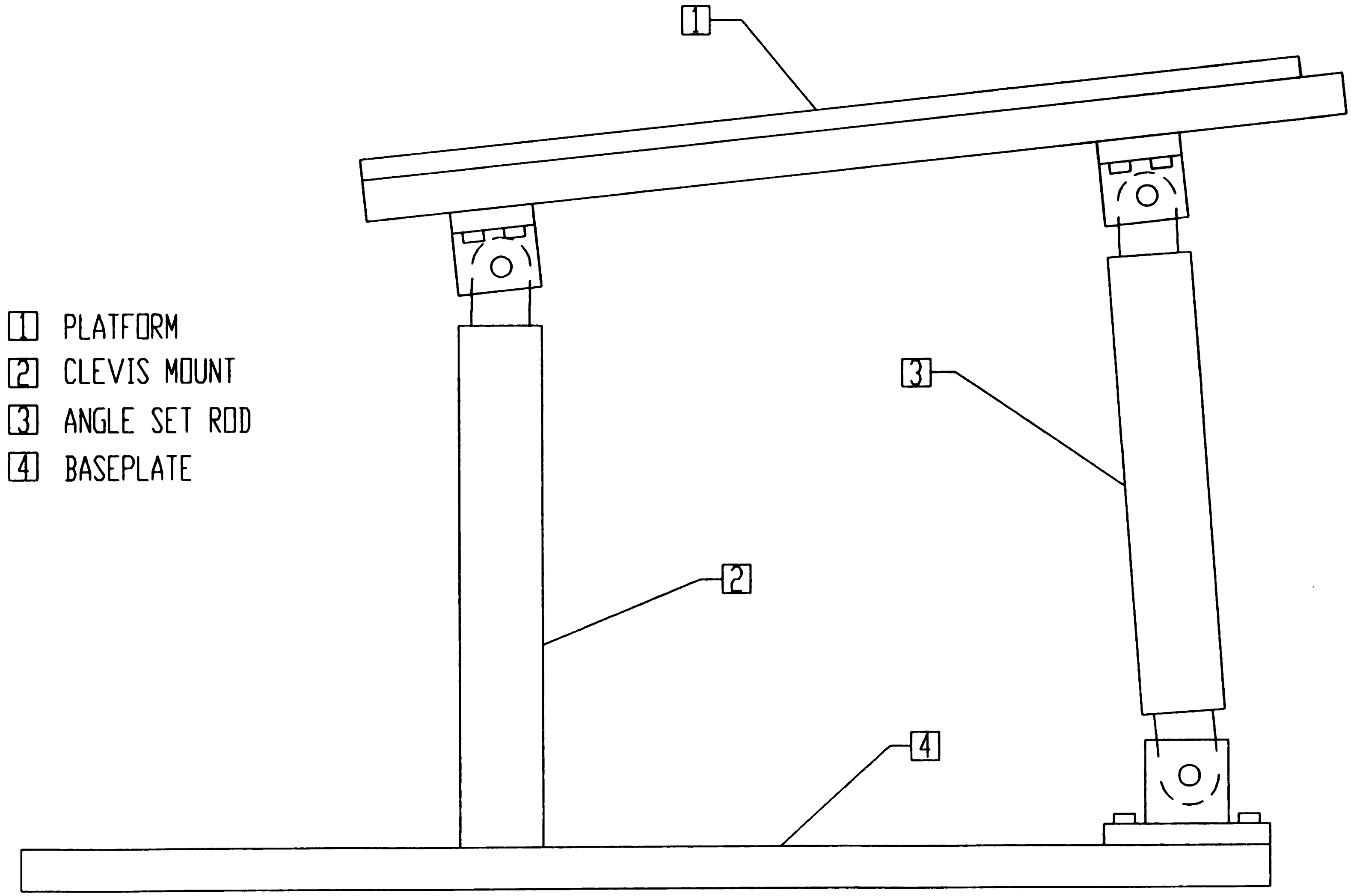

Figure 3. CONDUCTIVE SUPPORT BOARD

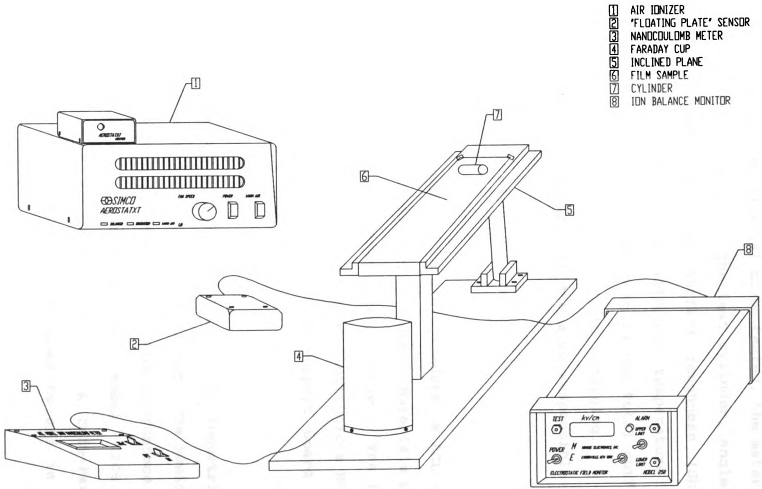

Figure 4. TEST CONFIGURATION

function of the packaging material to be tested, the material of the test cylinder, weight of the test cylinder, angle of inclination, contact area, and surface roughness (Shah, Martinez and Unger, 1988). In addition, temperature and relative humidity play a critical role in the total surface charge developed during triboelectric charging. The parameters described in Figure (1) are also responsible for the charge generated.

Test Equipment

To measure the charge generated on the cylinders, a ACL 1000 Nanocoulomb Meter and a Faraday cup were used. Materials were neutralized with Simco's Aerostatt XT air ionizer. The ions from the ionizer were monitored by Monroe Electronic's Model 258 Ion Balance Monitor. A conductive support board was fabricated from aluminum alloy.

The humidity chamber was assembled by Motter & Son Industries, Inc., of Ohio, in accordance with MIL-B-81705B. The humidity and temperature was controlled by a precision microprocessor based unit called a Hygrothermograph, Model 4205 by Hygrodynamics (Newport Scientific, Inc.). A Cole-Parmer Ultrasonic Cleaner Model 8845-5 was used to aid in the cleaning of the cylinders.

<u>Cylinders</u>

Twenty-four cylinders were made from two types of brass, two types of Teflon, and one type of quartz:

Brass -

B1 - less than a 50 micro-inch finish 1/2" diameter X 1" in length; weight = 27 grams.

B2 - 1/2" diameter X 7/8" in length; .042" wall brass tube per ASTM-B-135; weight = 7 grams.

Teflon -

T1 - General purpose Teflon conforming to AMS-3651; 1/2" diameter X 1" in length; weight = 7 grams.

T2 - Virgin Teflon MIL-P-19486A; 1/2" diameter X 1" in length; weight = 7 grams.

Quartz -

Q - GE type 214 with fire polish finish 12mm diameter X 1 " in length; weight = 7.5 grams.

The weight of the cylinders was measured with the Mettler AE 160 by Mettler Instrument Corporation. The weight of the cylinders are shown in Table 2.

Table 2. TEST CYLINDERS USED

TEST CYLINDER WEIGHTS
in grams

	QUARTZ	BRASS	BRASS ASTM - 7/8"	TEFLON general	TEFLON ASTM
1	7.46	27.32	6.96	6.92	7.04
2	7.45	26.98	6.98	6.94	7.03
3	7.46	27.30	6.97	6.93	7.02
4	7.51	27.02	6.97	6.94	7.03
5	7.55	26.83	6.97	6.95	7.02
6	7.54	27.27	6.97	6.94	7.04
7	7.55	27.37	6.96	6.95	7.01
8	7.48	27.33	6.97	6.96	7.04
9	7.51	27.06	6.97	6.93	7.01
10	7.54	26.84	6.96	6.98	7.01
11	7.54	27.26	6.97	6.92	6.99
12	7.53	26.86	6.97	6.95	7.04
13	7.48	26.98	6.97	6.94	7.02
14	7.45	26.75	6.97	6.94	7.02
15	7.48	27.35	6.97	6.95	7.02
16	7.56	27.00	6.97	6.91	7.04
17	7.54	26.90	6.96	6.91	7.03
18	7.55	27.32	6.97	6.94	7.00
19	7.54	26.99	6.96	6.93	7.02
20	7.50	27.00	6.97	6.94	7.01
21	7.54	26.96	6.97	6.96	7.03
22	7.54	27.25	6.97	6.96	7.01
23	7.54	26.88	6.97	6.94	7.04
24	7.57	26.96	6.98	6.94	7.01
AVG.	7.52	27.07	6.97	6.94	7.02
STD DEV	0.04	0.20	0.01	0.02	0.01

Film Materials

Thirty-six film samples were prepared; six samples of insulative film, twelve samples of conductive film, and eighteen samples of dissipative film. Each film sample was 3 inches wide by 13 1/2 inches long. Surface resistivity of the various film samples used were;

Supplier	Description	Surface Resistivity
Dow Chemical	Ziploc ® Storage Bags	> 10^{14} ohm/square
3M	Velostat Series 2000	5 X 10^{4} ohm/square
Cryovac	Sample 1*	5 X 10^{10} ohm/square
	Sample 2*	1 X 10^{14} ohm/square
	Sample 3	1 X 10^{14} ohm/square
	Sample 4	5 X 10^{6} ohm/square

* a cross-section view of the coextruded film materials are shown in Figure (5).

The film material and cylinder specifications for this experiment are shown in Table 3.

Test Procedures

Metal tongs were used to handle the cylinders and film samples during the cylinder cleaning and sample cutting process to eliminate possible contamination. All samples and cylinders were conditioned at 72° ± 5 degrees Fahrenheit, and at 12% ±

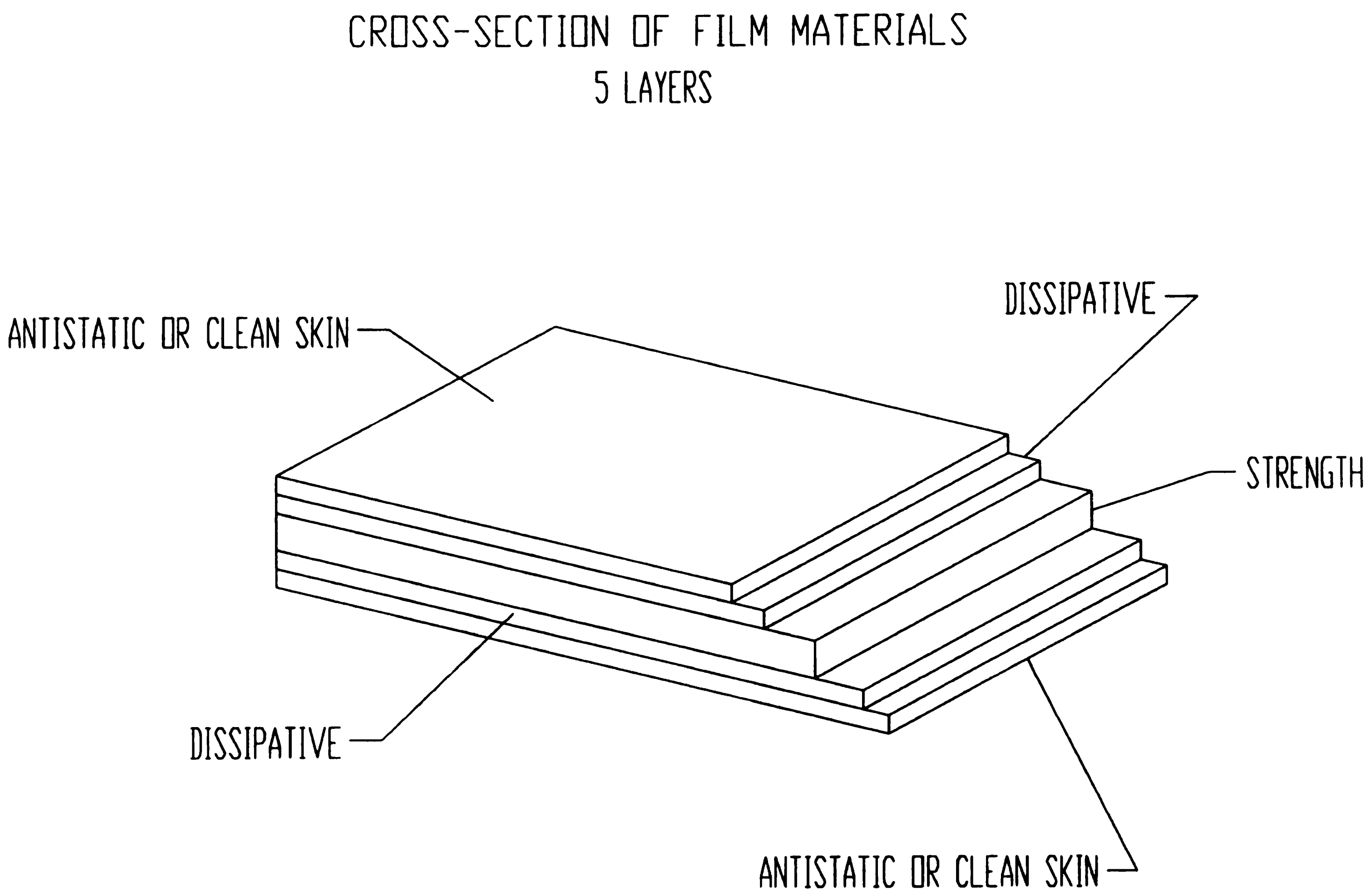

Figure 5. CROSS-SECTION OF COEXTRUDED FILM

Table 3. FILM MATERIAL AND CYLINDER SPECIFICATIONS

Material	Sample	Description	Class
1	1 thru 6	5×10^{10} ohm-square	D
2	1 thru 6	1×10^{14} ohm-square	D
3	1 thru 6	1×10^{14} ohm-square	D
4	1 thru 6	5×10^{6} ohm-square	C
5	1 thru 6	5×10^{4} ohm/square	C
6	1 thru 6	$> \times 10^{14}$ ohm-square	I

Cylinder Type	Description	Avg. Weight
Quartz - Q	GE type 214 w/ fire polish finish, 12mm diameter x 1"	7.52 g
Brass - B1	0.5" diameter x 1" < 50 micro-finish, general	27.07 g
B2	0.5" diameter x 7/8 " .042" wall, ASTM-B-135	6.97 g
Teflon - T1	General purpose - AMS-3651 0.5" diameter x 1"	6.94 g
T2	Virgin - MIL-P-19486A 0.5" diameter x 1"	7.02 g

D - Dissipative C - Conductive I - Insulative

3% RH for at least 48 hours. Testing was performed at the same conditions. All film samples were suspended in the humidity controlled chamber so that both sides of the film samples were exposed to these dry conditions.

Prior to use, each brass cylinder was cleaned in an ultrasonic bath filled with Bransonic oxide remover N-08801-35 for a period of 3 minutes. After removal from the cleaner, each brass cylinder was rinsed with deionized water from a Milli-Q Reagent Water System by Millipore Corporation. The brass cylinders were then rinsed with reagent grade methyl alcohol. All cylinders were than cleaned in the ultrasonic bath filled with Bransonic general purpose cleaner N-08801-15 for a period of 3 minutes. After removal from the bath, each cylinder was first rinsed with deionized water and then with methyl alcohol. All cylinders were placed in the humidity controlled chamber for conditioning.

The test procedure recommends that the angle of inclination of the conductive support board to be set at 15 degrees. For this study, the support board was set at varying degrees (5°, 10°, 15° and 20°) to the horizontal. The Faraday cup was positioned in such a way to allow the cylinders to roll down the inclined plane and fall directly into the Faraday cup without hitting the sides of the cup. The Faraday cup and conductive support board were grounded to avoid any charges that may have propagated prior to testing. Conductive cross-linked polyethylene foam, 3" diameter and 1/8" in thickness, was placed at the bottom of the Faraday cup to cushion the fall of the cylinders. The conductive polyethylene foam has a surface resistivity of 1.4×10^5 to 6.0×10^5 ohms/square. The air ionizer was turned on for ten minutes prior to testing to neutralize any local charges. The ion balance was adjusted to ± 5 volts on the charge plate monitor. Charges on both sides of the testing material were neutralized prior to fixing them to the support board.

The film samples were then affixed to the conductive plane using thin double sided tape at its four corners. The end of the film was folded under the support board to prevent any interference with the rolling cylinders. The film samples were again ionized after being placed on the conductive board to neutralize any charges that may have accumulated. The test cylinders were treated with the air ionizer before each roll. The ionizer was turned off before placing cylinders on the inclined plane. The Faraday cup was then zeroed and the cover of the Faraday cup was removed. Using grounded metal tongs, the cylinders were placed in the middle of the sample at the top of the test material. The cylinders were then released, rolling down the plane and falling into the Faraday cup. After the cylinder fell into the Faraday cup, the cover was replaced back on the Faraday cup and the charge measured.

3.0 DATA AND RESULTS

Thirty-six film samples were used in this experiment; six of the insulative, twelve of the conductive, and eighteen of the dissipative classification. Eighteen cylinders were used for the actual experiment. The remaining six cylinders functioned as back-ups in case any of the previous cylinders were damaged during the testing. Each film sample used one of each cylinder type (brass, quartz, and Teflon). Each cylinder type was rolled three times per test material at each degree of incline (5°, 10°, 15° and 20°) and using a new cylinder after each roll. Each cylinder and test material were neutralized with the air ionizer before each roll.

All the test data of the electrical charges generated by the cylinders are listed in Tables A-1 through A-24 (Appendix A). The average charges of each cylinder type; quartz, brass and Teflon measured in nanoCoulombs and corresponding standard deviations are exhibited in Tables 4 and 5 (pages 25 & 26).

The average charges per cylinder type for the conductive, dissipative and insulative film materials are presented in Figures 6 through 9 (pages 27-30). The average charges per cylinder type as a function of degree of inclination (5°, 10°, 15° and 20°) are listed in Figures 10 through 15 (pages 31-36).

The data shows that Teflon generates the most charge on all film materials. The two different grades of Teflon evaluated do not have a significant effect on charge generation since the mean values are very close to each other and the standard deviation is higher than the difference between mean values.

The charge on quartz cylinders tends to be positive for materials 2 thru 6. The charge on quartz for material 1 however, is very high in the negative direction. This is a dissipative material having a much lower surface resistivity.

The brass cylinders tend to develop small negative or small positive charges depending on the film material. Their readings were very close for both cylinder types evaluated on all the film samples tested except for materials 2 and 3. The heavier brass cylinder produced a much greater charge on these film materials than did the lighter brass cylinder. Both film samples are dissipative materials with higher surface resistivity.

The effect of the angle of incline was also evaluated. Cylinders released at the 20° angle were much more difficult to control on the support board, and they tended to skip rather than roll down the incline plane. There was more control at the 15° angle. In general, the angle of incline had a significant effect on the charge generated by all the cylinders investigated. The biggest difference in the charge generated for different release angles was observed using quartz cylinders on material 1. The mean charge increase from 5 degrees to 10 degrees was 39.0 percent; from 10 degrees to 15 degrees was 21.1 percent; and from 15 degrees to 20 degrees was 24.6 percent. This showed a total charge increase of 63.6 percent from 5 degrees to 20 degrees.

The angle of incline has a lesser effect for brass cylinders. The most significant charge from 5 degrees to 20 degrees was seen for material 3 (dissipative) which showed a 31.9 percent increase with the heavier brass cylinders.

The angle of incline also had a significant effect on the charge generated by both the Teflon cylinders, especially on material 6. The mean percent from 5 degrees to 20 degrees for T1 was 32.7 percent and for T2, 19.6 percent.

Further investigation found that by attaching an oxygen free high conductivity copper plate, 3 inches wide by 11.5 inches long and .031 inches thick, to the conductive board at a 15 degree incline, the charging tendencies of the film materials was significantly reduced. This was more evident with the Teflon cylinders. The copper plate was used to identify the possible effect of conductivity differences between copper and aluminum. Aluminum tends to oxidize, thus forming an oxidized layer which induces resistance to any electrical flow. Three rolls of each cylinder type on one of each film material was measured. These values are listed in Table 6 (page 37).

It was also found that a residual charge was generated on the cylinders when dropped directly into the Faraday cup after proper cleaning and ionization. This may have occurred due to the cylinders passing through the air. Although not recognized by the EIA, some triboelectric series charts list air at the uppermost position of the chart, the positive end. Some argue that air is neutral, since it comprises of 79% nitrogen, a neutral gas. Other particles such as dust, moisture, or even oxygen may have contributed to the residual charge as the cylinders passed through the air. Teflon developed the largest residual charge, brass a very small amount, and quartz averaged a zero charge. The quartz cylinders are closer to the positive end of the triboelectric series chart, therefore less of a charge is expected when falling through the air. Brass, being near the middle of the series, accumulated a small negative charge. Teflon is at the opposite spectrum of this series, and therefore shows a greater charge. A sample of eighteen drops was taken. These residual charges are listed in Table 7 (page 38).

Table 4. AVERAGE CHARGE OF EACH CYLINDER TYPE IN nC

	FILM MATERIAL 1				FILM MATERIAL 2		
Cylinder	Angle (deg)	Avg Charge	STDEV	Cylinder	Angle (deg)	Avg Charge	STDEV
Q	5	-0.25222	0.05558	Q	5	-0.01389	0.08346
B1		-0.10111	0.01779	B1		-0.00333	0.08630
B2		-0.07611	0.00979	B2		-0.06611	0.04767
T1		-0.47889	0.05051	T1		-0.42167	0.04369
T2		-0.49556	0.08053	T2		-0.43167	0.04950
Q	10	-0.41056	0.09991	Q	10	-0.01556	0.07594
B1		-0.12778	0.04081	B1		0.02667	0.06860
B2		-0.08500	0.01383	B2		-0.05000	0.04187
T1		-0.49000	0.05573	T1		-0.43056	0.07042
T2		-0.51722	0.05245	T2		-0.48389	0.06289
Q	15	-0.51944	0.15958	Q	15	0.01611	0.05337
B1		-0.13722	0.04824	B1		0.08611	0.05606
B2		-0.09000	0.01680	B2		-0.02333	0.03804
T1		-0.49778	0.06330	T1		-0.43778	0.08782
T2		-0.49778	0.03639	T2		-0.46500	0.08002
Q	20	-0.69333	0.16205	Q	20	0.10500	0.01689
B1		-0.15556	0.01886	B1		0.09278	0.03140
B2		-0.09111	0.01231	B2		-0.00111	0.03579
T1		-0.53889	0.08560	T1		-0.43500	0.10066
T2		-0.54278	0.06470	T2		-0.42000	0.04229

	FILM MATERIAL 3				FILM MATERIAL 4		
Cylinder	Angle (deg)	Avg Charge	STDEV	Cylinder	Angle (deg)	Avg Charge	STDEV
Q	5	0.20722	0.08123	Q	5	0.13667	0.06136
B1		0.49167	0.10217	B1		-0.03389	0.00979
B2		0.08111	0.08094	B2		-0.03556	0.00984
T1		-0.42444	0.05793	T1		-0.40167	0.06810
T2		-0.38389	0.07163	T2		-0.39944	0.08755
Q	10	0.23722	0.09215	Q	10	0.12222	0.06735
B1		0.42778	0.09302	B1		-0.03889	0.02111
B2		0.08111	0.07177	B2		-0.03222	0.00647
T1		-0.41944	0.05906	T1		-0.40278	0.07706
T2		-0.45833	0.06109	T2		-0.41167	0.10755
Q	15	0.21056	0.10183	Q	15	0.08444	0.06061
B1		0.39722	0.08407	B1		-0.03556	0.00784
B2		0.08944	0.07996	B2		-0.03222	0.00647
T1		-0.41778	0.04989	T1		-0.46333	0.10928
T2		-0.43556	0.07740	T2		-0.44889	0.11156
Q	20	0.45667	0.05099	Q	20	0.03778	0.02602
B1		0.71722	0.23384	B1		0.00944	0.01110
B2		0.16056	0.09686	B2		0.00667	0.01283
T1		-0.35389	0.04840	T1		-0.38333	0.04015
T2		-0.35500	0.05448	T2		-0.38556	0.05554

Q - Quartz B1 & B2 - Brass T1 & T2 - Teflon

Table 5. AVERAGE CHARGE OF EACH CYLINDER TYPE in nC (Continued)

FILM MATERIAL 5				FILM MATERIAL 6			
Cylinder	Angle (deg)	Avg Charge	STDEV	Cylinder	Angle (deg)	Avg Charge	STDEV
Q	5	0.35000	0.07844	Q	5	0.13722	0.10543
B1		-0.03722	0.00826	B1		-0.01000	0.18234
B2		-0.03222	0.00732	B2		-0.05833	0.07548
T1		-0.42556	0.04643	T1		-0.36556	0.06989
T2		-0.47611	0.05731	T2		-0.44944	0.10903
Q	10	0.30000	0.08110	Q	10	0.14722	0.10162
B1		-0.03778	0.00647	B1		-0.06889	0.18528
B2		-0.03389	0.00502	B2		-0.09611	0.05500
T1		-0.44556	0.05554	T1		-0.39611	0.10589
T2		-0.47500	0.04176	T2		-0.43944	0.09771
Q	15	0.34889	0.10017	Q	15	0.14056	0.08003
B1		-0.03167	0.00707	B1		-0.08444	0.16425
B2		-0.03167	0.00514	B2		-0.08389	0.06326
T1		-0.46000	0.04947	T1		-0.42278	0.13839
T2		-0.48056	0.04007	T2		-0.48722	0.13455
Q	20	0.30667	0.02612	Q	20	0.07167	0.02550
B1		-0.00278	0.00826	B1		-0.01722	0.09329
B2		-0.00278	0.01179	B2		-0.08056	0.02014
T1		-0.42667	0.05053	T1		-0.55111	0.07427
T2		-0.44111	0.03359	T2		-0.56444	0.13496

Q - Quartz B1 & B2 - Brass T1 & T2 - Teflon

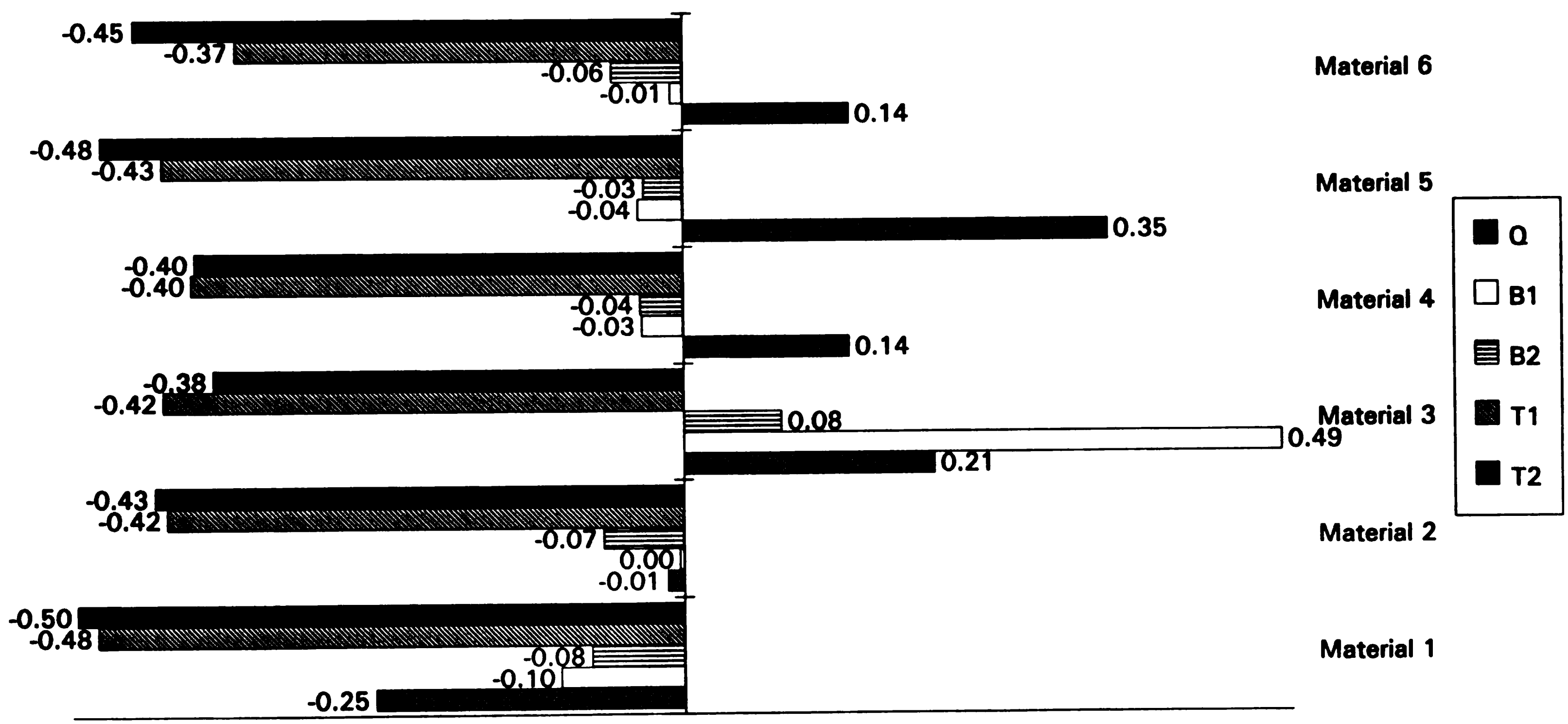

Figure 6. AVERAGE CHARGE PER CYLINDER vs. MATERIAL @ 5 DEGREES

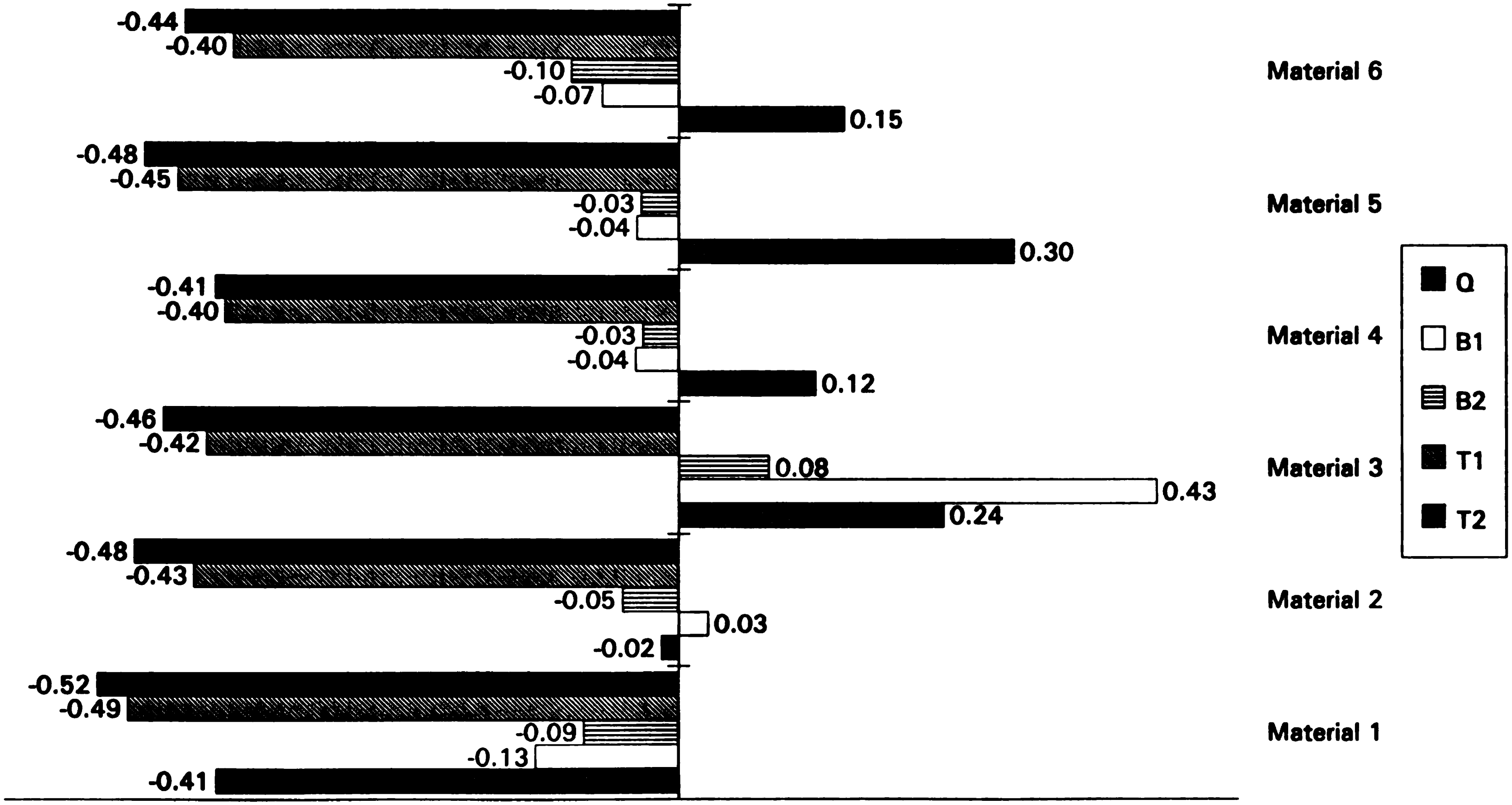

Figure 7. AVERAGE CHARGE PER CYLINDER TYPE vs. MATERIAL @ 10 DEGREES

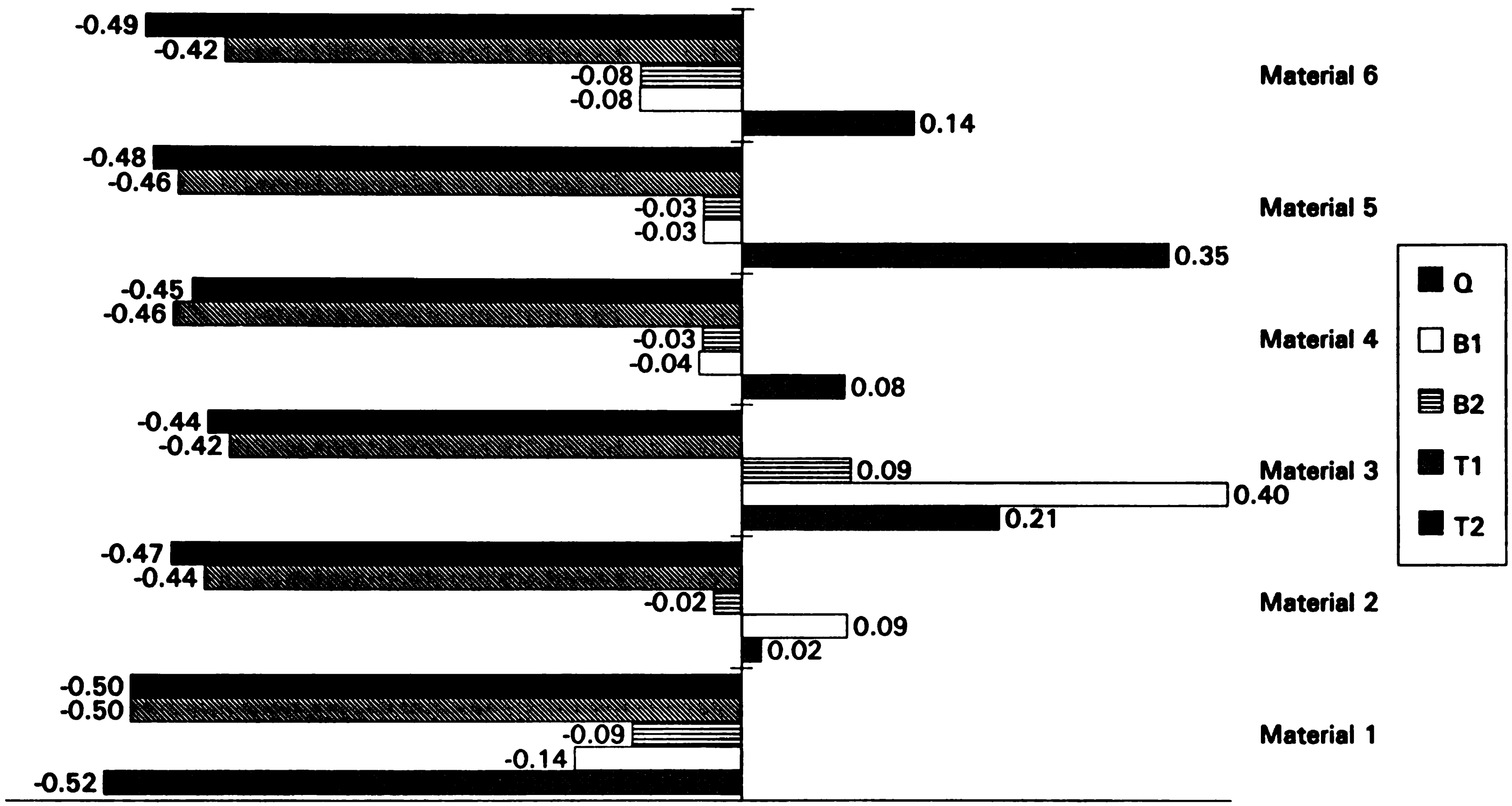

Figure 8. AVERAGE CHARGE PER CYLINDER TYPE vs. MATERIAL @ 15 DEGREES

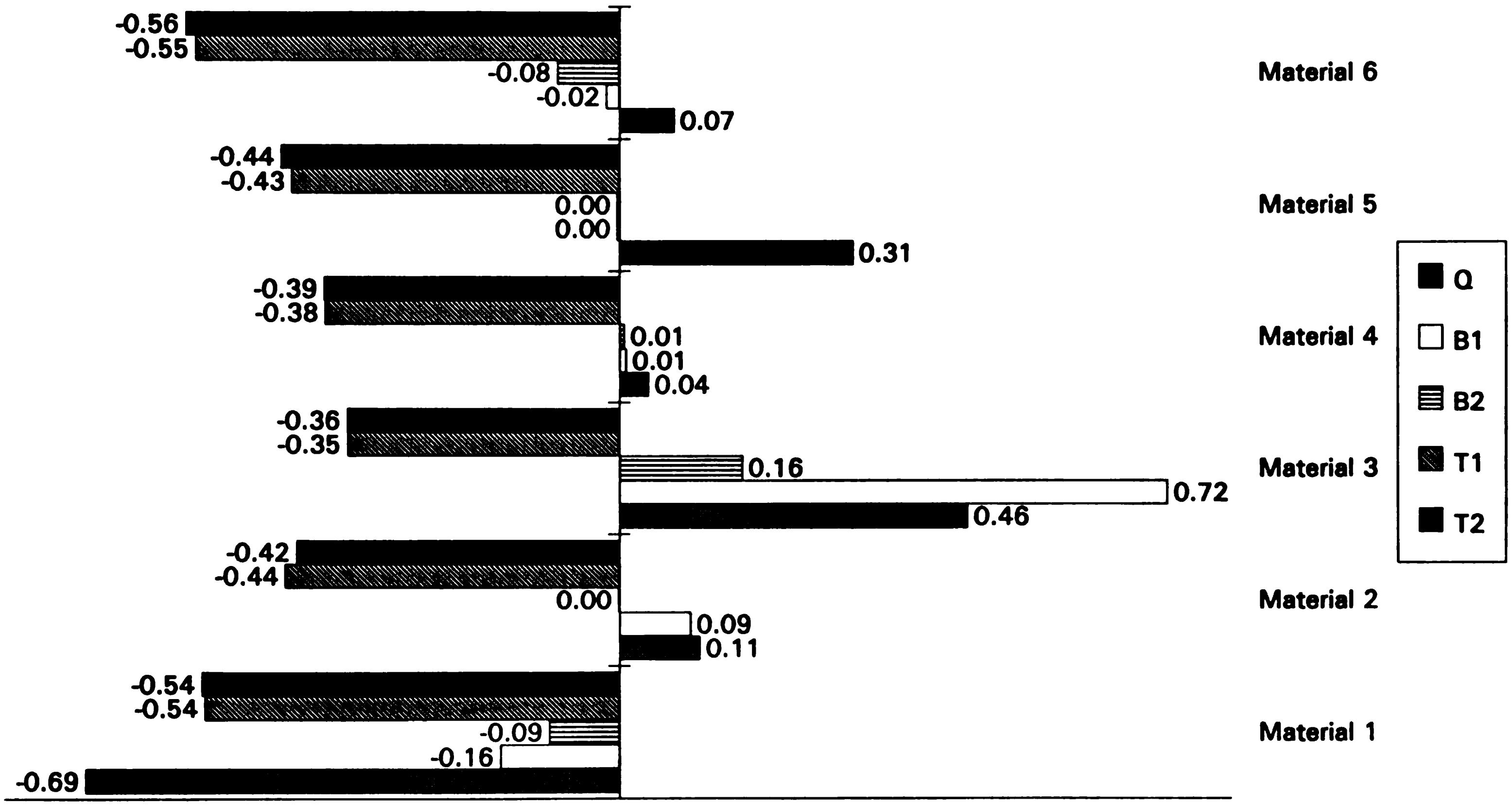

Figure 9. AVERAGE CHARGE PER CYLINDER TYPE vs. MATERIAL @ 20 DEGREES

MATERIAL 1 (DISSIPATIVE)

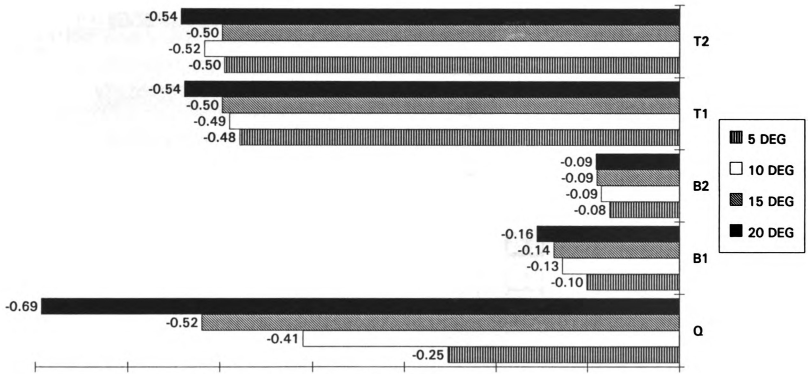

Figure 10. AVERAGE CHARGE PER CYLINDER TYPE vs. DEGREE OF RELEASE FOR MATERIAL 1

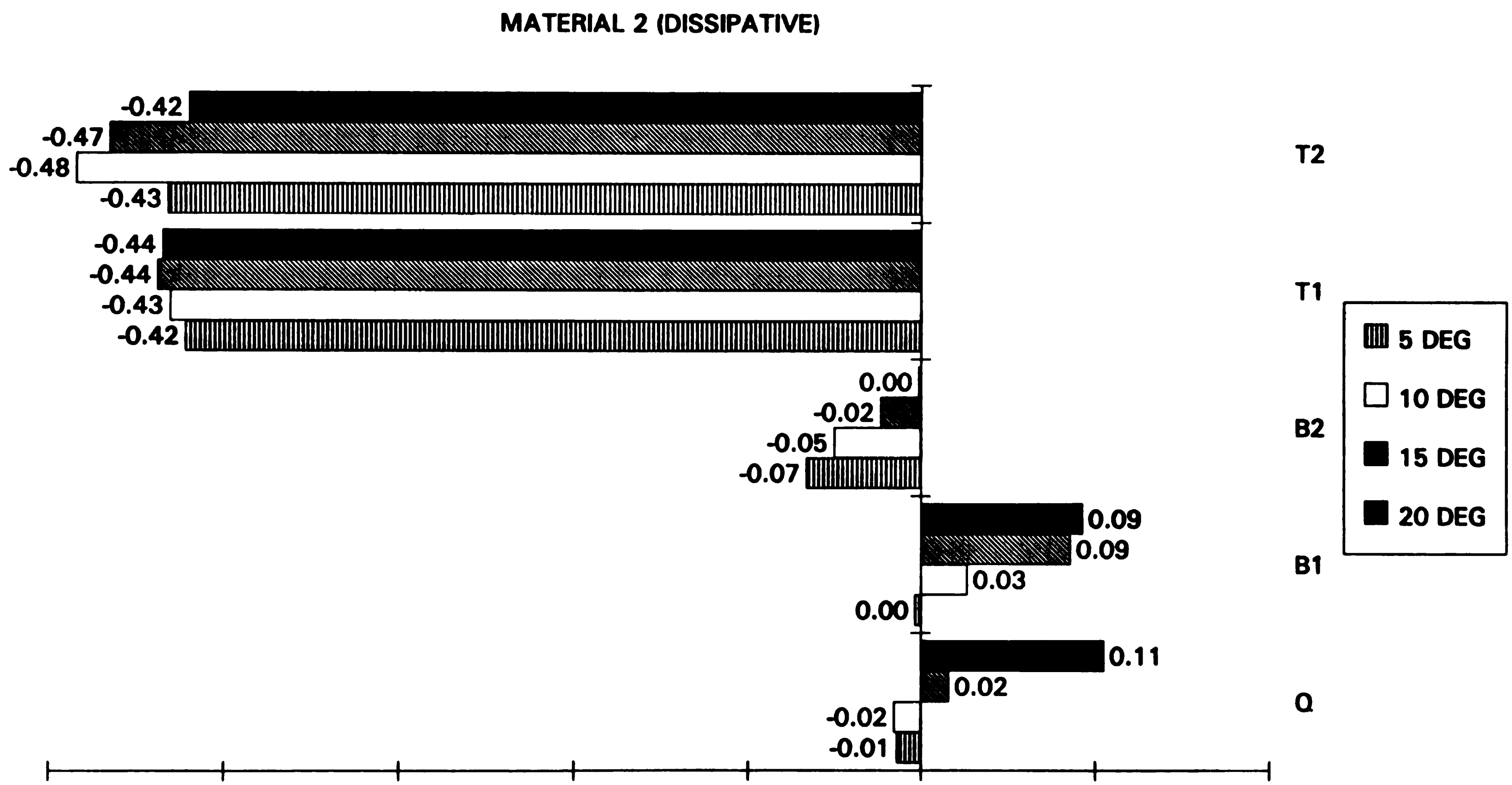

Figure 11. AVERAGE CHARGE PER CYLINDER TYPE vs. DEGREE OF RELEASE FOR MATERIAL 2

MATERIAL 3 (DISSIPATIVE)

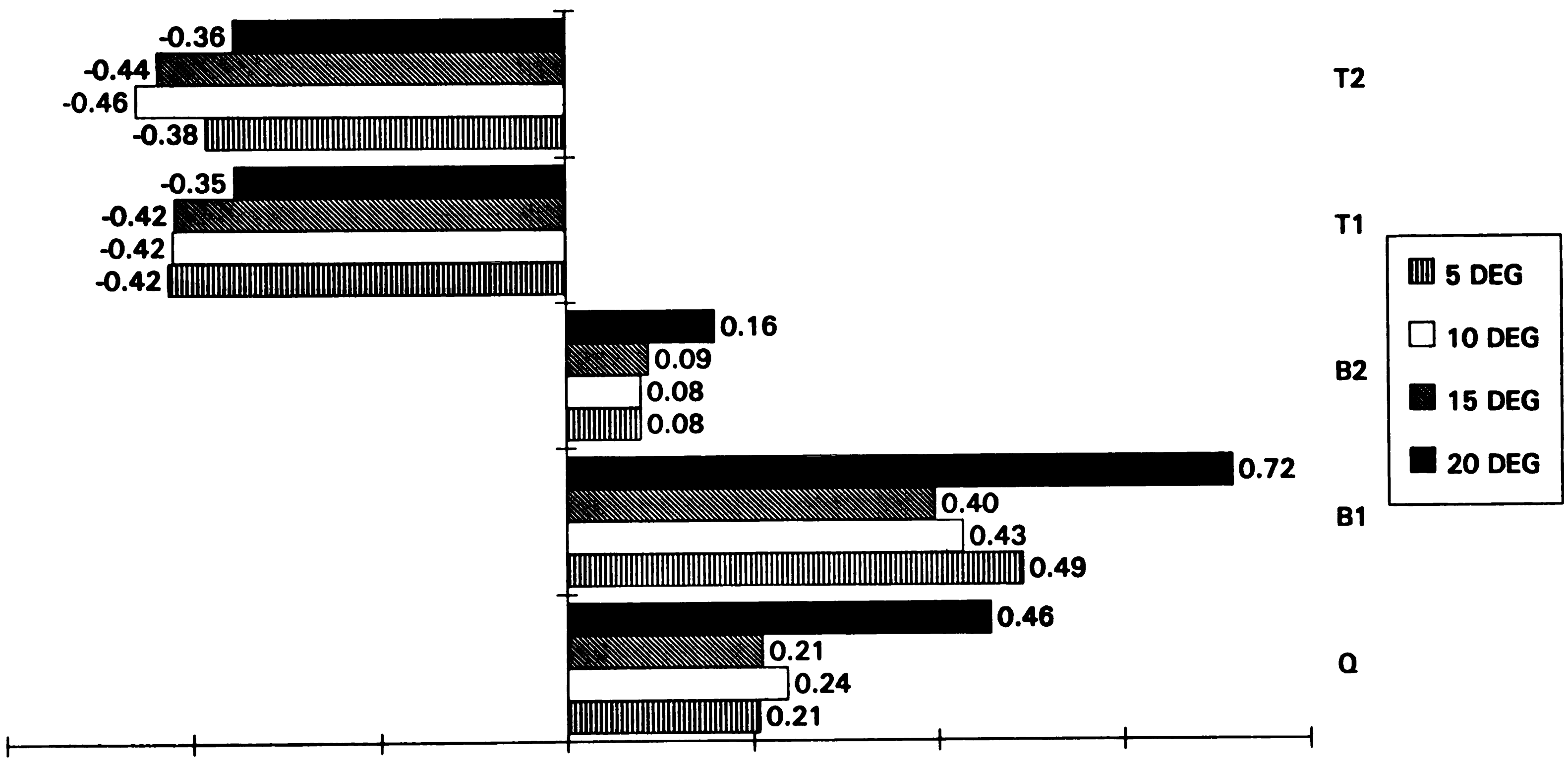

Figure 12. AVERAGE CHARGE PER CYLINDER TYPE vs. DEGREE OF RELEASE FOR MATERIAL 3

MATERIAL 4 (CONDUCTIVE)

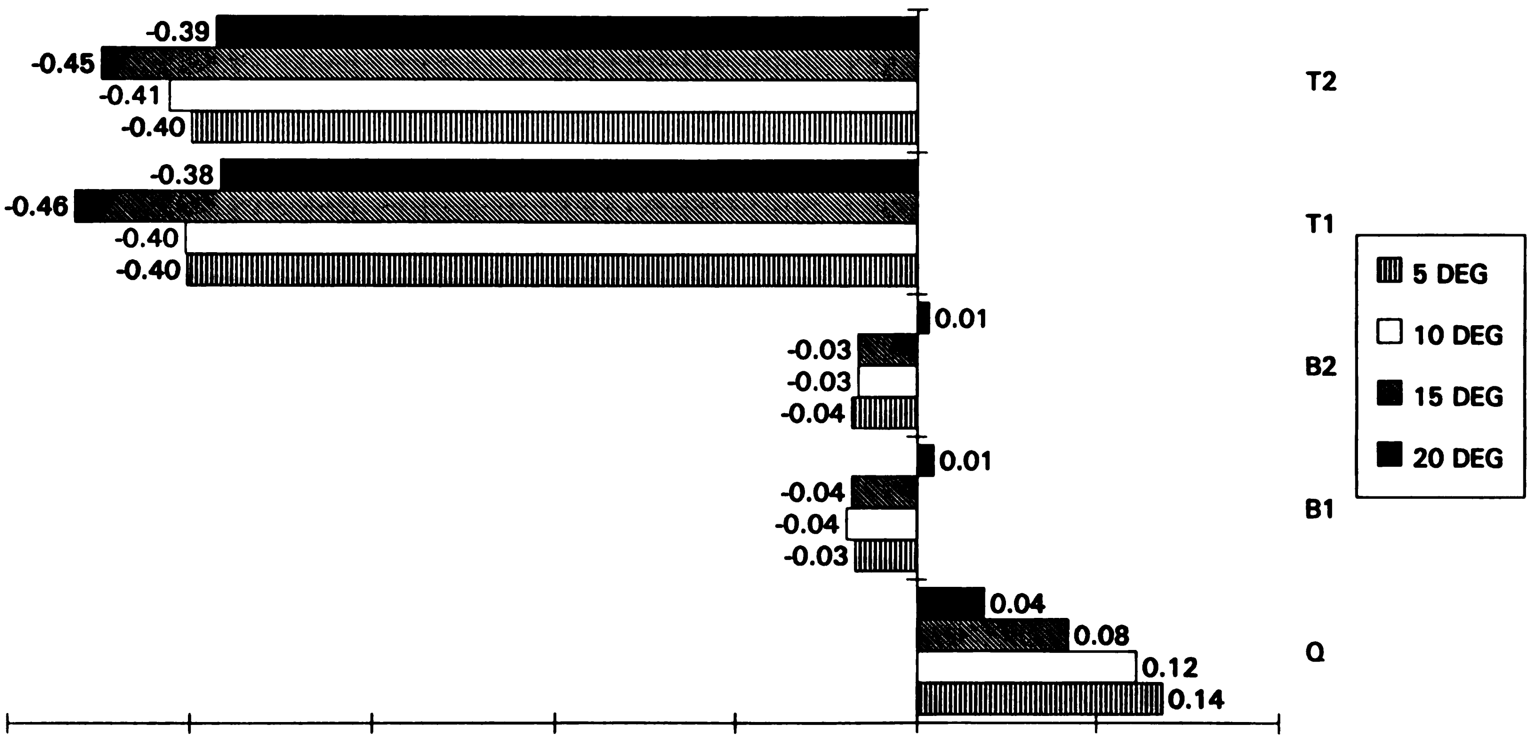

Figure 13. AVERAGE CHARGE PER CYLINDER TYPE vs. DEGREE OF RELEASE FOR MATERIAL 4

MATERIAL 5 (CONDUCTIVE)

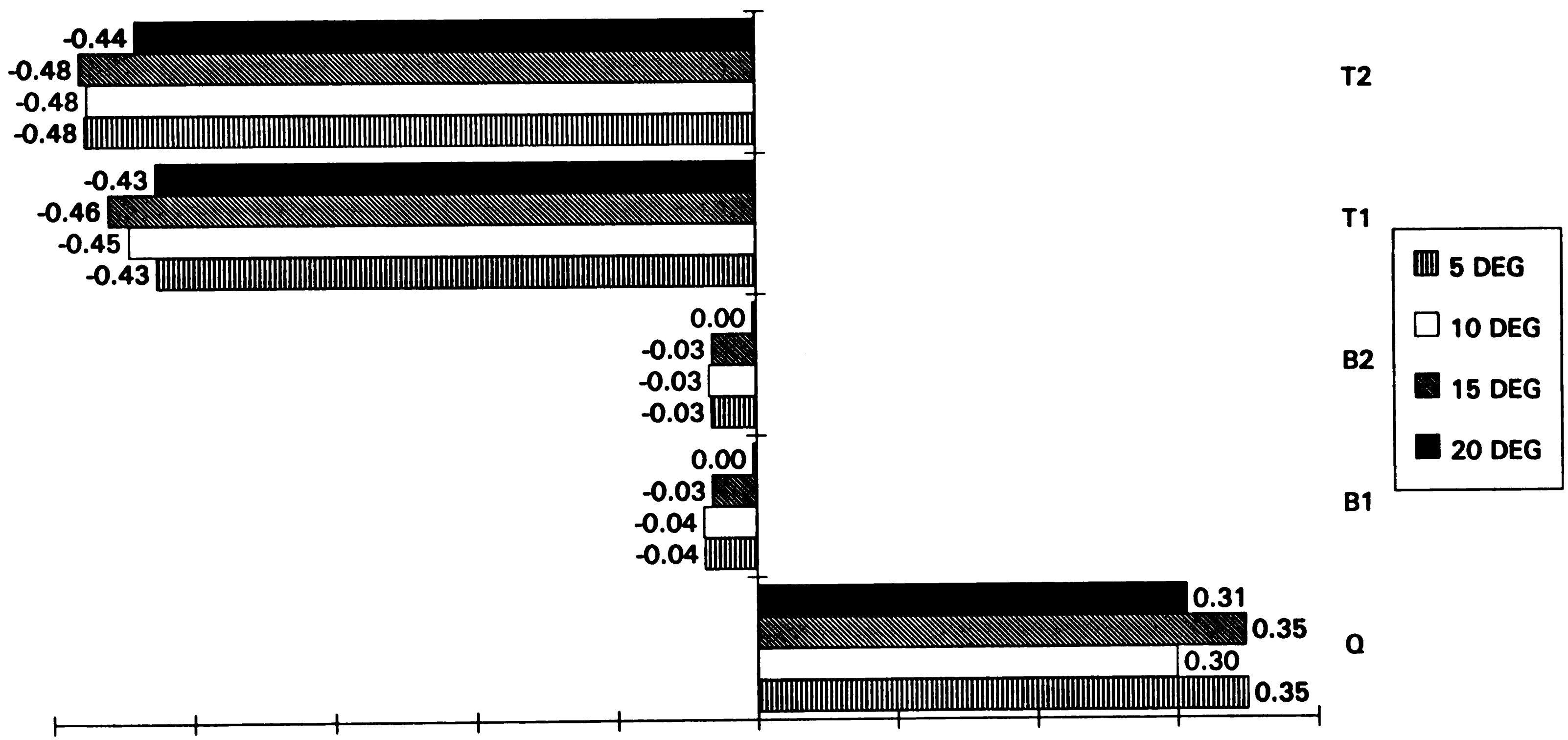

Figure 14. AVERAGE CHARGE PER CYLINDER TYPE vs. DEGREE OF RELEASE FOR MATERIAL 5

MATERIAL 6 (INSULATIVE)

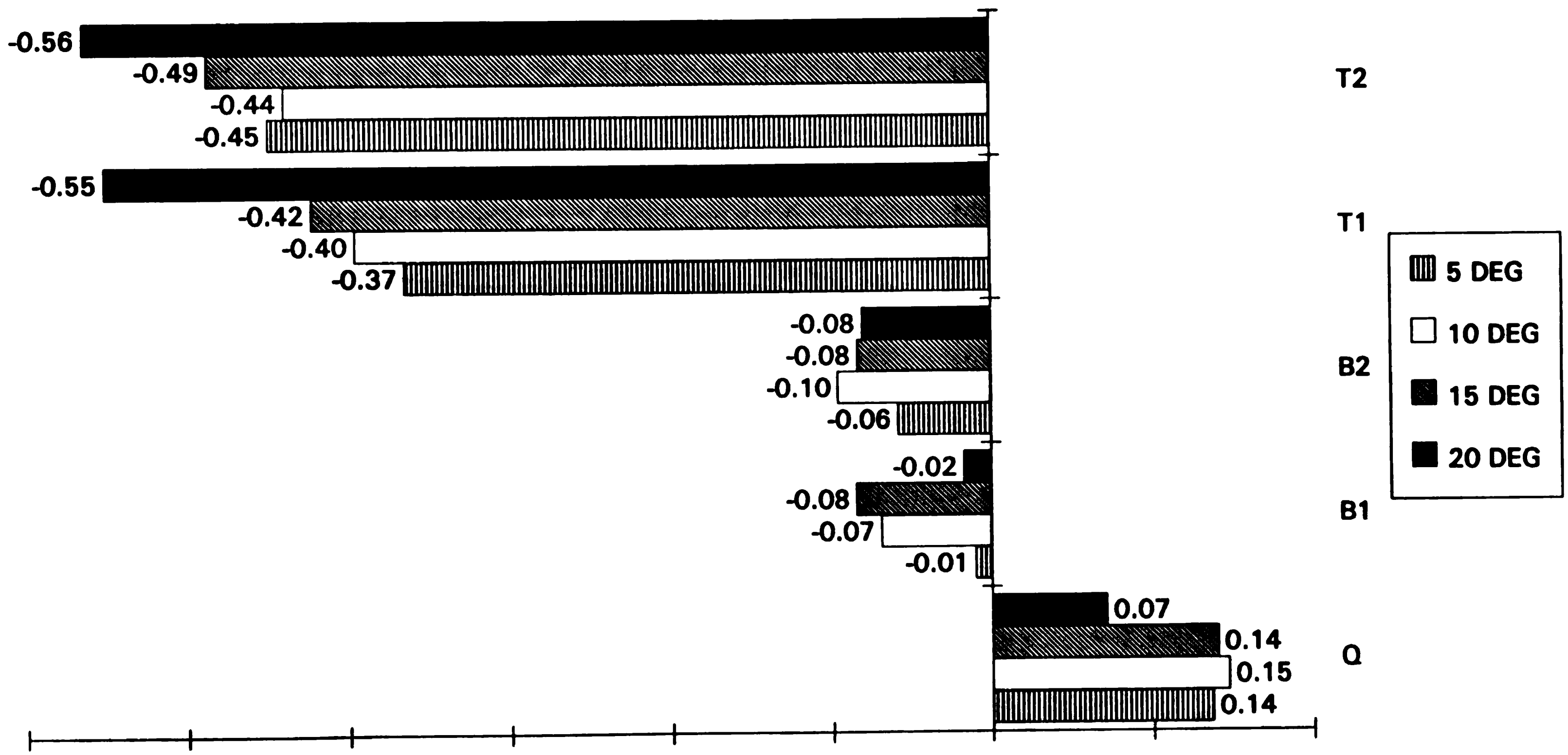

Figure 15. AVERAGE CHARGE PER CYLINDER TYPE vs. DEGREE OF RELEASE FOR MATERIAL 6

Table 6. CHARGING OF ALL FILM ON COPPER PLATE IN nC. INCLINE PLANE @ 15 DEGREES

Film Material	Sample	Cylinders					
			roll 1	roll 2	roll 3	AVG	STDEV
Material 1	1	Q	-0.26	-0.29	-0.18	0.24333	0.05686
		B1	-0.20	-0.17	-0.15	0.17333	0.02517
		B2	-0.09	-0.08	-0.08	0.08333	0.00577
		T1	-0.43	-0.43	-0.37	0.41000	0.03464
		T2	-0.45	-0.42	-0.41	0.42667	0.02082
			roll 1	roll 2	roll 3	AVG	STDEV
Material 2	1	Q	0.04	0.02	0.11	0.05667	0.04726
		B1	0.18	0.13	0.15	0.15333	0.02517
		B2	0.02	0.06	0.08	0.05333	0.03055
		T1	-0.35	-0.35	-0.40	0.36667	0.02887
		T2	-0.33	-0.32	-0.35	0.33333	0.01528
			roll 1	roll 2	roll 3	AVG	STDEV
Material 3	1	Q	0.31	0.30	0.26	0.29000	0.02646
		B1	0.50	0.56	0.66	0.57333	0.08083
		B2	0.30	0.32	0.25	0.29000	0.03606
		T1	-0.22	-0.26	-0.21	0.23000	0.02646
		T2	-0.28	-0.38	-0.25	0.30333	0.06807
			roll 1	roll 2	roll 3	AVG	STDEV
Material 4	1	Q	0.18	0.09	0.14	0.13667	0.04509
		B1	-0.03	-0.02	-0.02	0.02333	0.00577
		B2	-0.02	-0.02	-0.03	0.02333	0.00577
		T1	-0.35	-0.38	-0.32	0.35000	0.03000
		T2	-0.38	-0.30	-0.37	0.35000	0.04359
			roll 1	roll 2	roll 3	AVG	STDEV
Material 5	1	Q	0.29	0.28	0.34	0.30333	0.03215
		B1	-0.03	-0.02	-0.02	0.02333	0.00577
		B2	-0.03	-0.03	-0.03	0.03000	0.00000
		T1	-0.37	-0.31	-0.35	0.34333	0.03055
		T2	-0.43	-0.34	-0.36	0.37667	0.04726
			roll 1	roll 2	roll 3	AVG	STDEV
Material 6	1	Q	0.04	0.04	0.09	0.05667	0.02887
		B1	0.04	-0.07	-0.16	0.06333	0.10017
		B2	-0.09	-0.03	-0.11	0.07667	0.04163
		T1	-0.40	-0.25	-0.33	0.32667	0.07506
		T2	-0.37	-0.39	-0.37	0.37667	0.01155

Q - Quartz B1 & B2 - Brass T1 & T2 - Teflon

Table 7. RESIDUAL CHARGE OF INDIVIDUAL CYLINDERS

Cylinders			
	drop 1	drop 2	drop 3
Q	-0.03	-0.01	-0.02
B1	-0.04	-0.04	-0.04
B2	-0.03	-0.02	-0.03
T1	-0.32	-0.30	-0.39
T2	-0.29	-0.29	-0.25
	drop 4	drop 5	drop 6
Q	0.03	-0.01	-0.01
B1	-0.05	-0.04	-0.04
B2	-0.04	-0.04	-0.03
T1	-0.32	-0.33	-0.32
T2	-0.25	-0.22	-0.15
	drop 7	drop 8	drop 9
Q	0.02	-0.01	0.01
B1	-0.04	-0.03	-0.04
B2	-0.03	-0.03	-0.03
T1	-0.25	-0.39	-0.35
T2	-0.21	-0.25	-0.21
	drop 10	drop 11	drop 12
Q	0.04	0.03	0.03
B1	-0.04	-0.04	-0.03
B2	-0.03	-0.03	-0.03
T1	-0.29	-0.30	-0.33
T2	-0.29	-0.28	-0.25
	drop 13	drop 14	drop15
Q	0.02	-0.01	-0.01
B1	-0.04	-0.04	-0.05
B2	-0.03	-0.04	-0.03
T1	-0.36	-0.32	-0.32
T2	-0.25	-0.29	-0.26
	drop 16	drop 17	drop 18
Q	0.00	-0.01	-0.01
B1	-0.04	-0.04	-0.04
B2	-0.03	-0.03	-0.04
T1	-0.38	-0.27	-0.32
T2	-0.21	-0.25	-0.23
		AVG	STDEV
Q	Quartz	0.00278	0.02052
B1	Brass	-0.04000	0.00485
B2	Brass	-0.03167	0.00514
T1	Teflon	-0.32556	0.03807
T2	Teflon	-0.24611	0.03696

4.0 CONCLUSION

This investigation attempted to examine the reliability of a possible test procedure for quantifying the triboelectric charging tendencies of conductive, dissipative and insulative film materials against various cylinders made of quartz, brass and Teflon. It also looked at the effect of cylinder weight and the effect of angle release.

The research found that there is not a significant difference between the various film material classifications in the generation of a triboelectric charge. It appears that the variation of surface resistivity between film materials has little to do with the material's tendency to acquire a charge when contacted by or rubbed against another material.

The effect of cylinder types does show a significant effect with Teflon generating the highest negative charge on all film materials. However, there is no significant difference between the general purpose and virgin types of Teflon cylinders evaluated.

There is a significant effect of cylinder weight between the two brass cylinders. The heavier brass cylinders produced a larger charge than the lighter cylinders, especially for the dissipative materials. Therefore, the test procedure should identify acceptable weight tolerances for cylinders used in the test protocol.

The angle of release does show significant charging effects with the increase in degree of incline. This is most significant with quartz cylinders on dissipative and insulative films. This effect is less significant when evaluating conductive films. Teflon also developed an increase in charge on the insulative film as the angle of release increased. The charge generated on the insulative film material 6 should yield a higher charge due to the high surface resistivity of the film, and the higher angle of release which relates to the separating speed of the electrons from the two objects in contact, thus not allowing the recombination of the electrons.

Areas for future research may be to construct a conductive board out of copper since copper does not form a oxidized layer distinctive with aluminum. This oxidation effect increases the resistance of the support board thus preventing any charges that are developed on the film to bleed off onto the support board. Another area for research would be to measure the residual charging influence of the various cylinders when dropped at controlled heights to see if air does play a role in the triboelectric effect.

APPENDIX

Table A-1. CHARGING PROPENSITY OF MATERIAL 1 IN nC. INCLINE PLANE @ 5 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
1	1	Q	-0.27	-0.20	-0.12
		B1	-0.13	-0.14	-0.14
		B2	-0.09	-0.10	-0.09
		T1	-0.55	-0.49	-0.46
		T2	-0.46	-0.45	-0.52
			roll 1	roll 2	roll 3
	2	Q	-0.23	-0.25	-0.30
		B1	-0.10	-0.10	-0.10
		B2	-0.07	-0.07	-0.07
		T1	-0.43	-0.51	-0.46
		T2	-0.45	-0.51	-0.45
			roll 1	roll 2	roll 3
	3	Q	-0.35	-0.24	-0.31
		B1	-0.10	-0.10	-0.10
		B2	-0.08	-0.08	-0.08
		T1	-0.46	-0.46	-0.60
		T2	-0.48	-0.45	-0.68
			roll 1	roll 2	roll 3
	4	Q	-0.33	-0.31	-0.27
		B1	-0.10	-0.09	-0.09
		B2	-0.07	-0.07	-0.07
		T1	-0.49	-0.56	-0.52
		T2	-0.53	-0.54	-0.70
			roll 1	roll 2	roll 3
	5	Q	-0.23	-0.23	-0.20
		B1	-0.08	-0.08	-0.09
		B2	-0.07	-0.07	-0.06
		T1	-0.44	-0.45	-0.44
		T2	-0.48	-0.47	-0.43
			roll 1	roll 2	roll 3
	6	Q	-0.20	-0.25	-0.25
		B1	-0.09	-0.10	-0.09
		B2	-0.08	-0.08	-0.07
		T1	-0.44	-0.42	-0.44
		T2	-0.45	-0.38	-0.49

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-2. CHARGING PROPENSITY OF MATERIAL 1 IN nC. INCLINE PLANE @ 10 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
1	1	Q	-0.38	-0.35	-0.14
		B1	-0.25	-0.18	-0.17
		B2	-0.11	-0.11	-0.11
		T1	-0.48	-0.57	-0.58
		T2	-0.55	-0.51	-0.54
			roll 1	roll 2	roll 3
	2	Q	-0.45	-0.49	-0.39
		B1	-0.15	-0.13	-0.14
		B2	-0.08	-0.09	-0.08
		T1	-0.48	-0.50	-0.50
		T2	-0.45	-0.50	-0.51
			roll 1	roll 2	roll 3
	3	Q	-0.60	-0.43	-0.52
		B1	-0.12	-0.13	-0.12
		B2	-0.08	-0.10	-0.08
		T1	-0.60	-0.43	-0.47
		T2	-0.48	-0.55	-0.64
			roll 1	roll 2	roll 3
	4	Q	-0.46	-0.49	-0.42
		B1	-0.13	-0.10	-0.11
		B2	-0.08	-0.08	-0.08
		T1	-0.42	-0.44	-0.48
		T2	-0.51	-0.51	-0.47
			roll 1	roll 2	roll 3
	5	Q	-0.37	-0.37	-0.36
		B1	-0.08	-0.10	-0.09
		B2	-0.07	-0.08	-0.06
		T1	-0.57	-0.44	-0.50
		T2	-0.47	-0.53	-0.57
			roll 1	roll 2	roll 3
	6	Q	-0.50	-0.36	-0.31
		B1	-0.10	-0.11	-0.09
		B2	-0.08	-0.08	-0.08
		T1	-0.43	-0.48	-0.45
		T2	-0.43	-0.49	-0.60

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-3. CHARGING PROPENSITY OF MATERIAL 1 IN nC. INCLINE PLANE @ 15 DEGREES

Material	Sample	Cylinders	roll 1	roll 2	roll 3
1	1	Q	-0.45	-0.33	-0.14
		B1	-0.26	-0.21	-0.22
		B2	-0.12	-0.13	-0.12
		T1	-0.48	-0.52	-0.58
		T2	-0.52	-0.53	-0.48
			roll 1	roll 2	roll 3
	2	Q	-0.56	-0.52	-0.43
		B1	-0.14	-0.12	-0.14
		B2	-0.09	-0.08	-0.09
		T1	-0.54	-0.50	-0.49
		T2	-0.48	-0.58	-0.50
			roll 1	roll 2	roll 3
	3	Q	-0.82	-0.54	-0.68
		B1	-0.14	-0.14	-0.16
		B2	-0.09	-0.09	-0.10
		T1	-0.53	-0.46	-0.54
		T2	-0.54	-0.55	-0.47
			roll 1	roll 2	roll 3
	4	Q	-0.55	-0.70	-0.60
		B1	-0.13	-0.12	-0.12
		B2	-0.08	-0.08	-0.08
		T1	-0.43	-0.57	-0.42
		T2	-0.48	-0.46	-0.53
			roll 1	roll 2	roll 3
	5	Q	-0.49	-0.39	-0.32
		B1	-0.09	-0.09	-0.10
		B2	-0.08	-0.08	-0.07
		T1	-0.44	-0.45	-0.40
		T2	-0.44	-0.50	-0.48
			roll 1	roll 2	roll 3
	6	Q	-0.61	-0.61	-0.61
		B1	-0.10	-0.09	-0.10
		B2	-0.08	-0.08	-0.08
		T1	-0.62	-0.43	-0.56
		T2	-0.48	-0.47	-0.47

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-4. CHARGING PROPENSITY OF MATERIAL 1 IN nC. INCLINE PLANE @ 20 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
1	1	Q	-0.68	-0.75	-0.72
		B1	-0.19	-0.17	-0.15
		B2	-0.08	-0.11	-0.09
		T1	-0.42	-0.50	-0.51
		T2	-0.53	-0.49	-0.46
			roll 1	roll 2	roll 3
	2	Q	-0.96	-0.84	-0.58
		B1	-0.18	-0.18	-0.14
		B2	-0.08	-0.09	-0.09
		T1	-0.51	-0.66	-0.61
		T2	-0.55	-0.44	-0.56
			roll 1	roll 2	roll 3
	3	Q	-0.84	-0.92	-0.79
		B1	-0.14	-0.16	-0.13
		B2	-0.09	-0.09	-0.10
		T1	-0.51	-0.43	-0.78
		T2	-0.54	-0.46	-0.49
			roll 1	roll 2	roll 3
	4	Q	-0.50	-0.54	-0.45
		B1	-0.17	-0.14	-0.15
		B2	-0.09	-0.08	-0.08
		T1	-0.53	-0.49	-0.56
		T2	-0.58	-0.54	-0.63
			roll 1	roll 2	roll 3
	5	Q	-0.46	-0.59	-0.89
		B1	-0.14	-0.14	-0.16
		B2	-0.13	-0.09	-0.09
		T1	-0.59	-0.55	-0.54
		T2	-0.53	-0.58	-0.66
			roll 1	roll 2	roll 3
	6	Q	-0.59	-0.79	-0.59
		B1	-0.18	-0.15	-0.13
		B2	-0.08	-0.09	-0.09
		T1	-0.51	-0.44	-0.56
		T2	-0.59	-0.49	-0.65

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-5. CHARGING PROPENSITY OF MATERIAL 2 IN nC. INCLINE PLANE @ 5 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
2	1	Q	0.04	-0.03	0.04
		B1	0.06	0.10	0.17
		B2	-0.04	-0.06	0.04
		T1	-0.42	-0.43	-0.44
		T2	-0.40	-0.42	-0.40
			roll 1	roll 2	roll 3
	2	Q	-0.03	0.01	-0.04
		B1	0.06	0.03	0.03
		B2	-0.05	-0.06	-0.01
		T1	-0.43	-0.45	-0.39
		T2	-0.39	-0.38	-0.39
			roll 1	roll 2	roll 3
	3	Q	-0.14	-0.18	-0.15
		B1	0.01	-0.04	-0.06
		B2	-0.07	-0.06	-0.06
		T1	-0.43	-0.32	-0.40
		T2	-0.38	-0.43	-0.50
			roll 1	roll 2	roll 3
	4	Q	-0.06	0.02	0.10
		B1	0.04	-0.06	-0.10
		B2	-0.10	-0.08	-0.07
		T1	-0.41	-0.41	-0.46
		T2	-0.36	-0.51	-0.44
			roll 1	roll 2	roll 3
	5	Q	-0.04	-0.05	0.00
		B1	0.06	0.03	0.01
		B2	-0.04	-0.07	-0.03
		T1	-0.40	-0.36	-0.43
		T2	-0.42	-0.54	-0.48
			roll 1	roll 2	roll 3
	6	Q	0.08	0.09	0.09
		B1	-0.12	-0.13	-0.15
		B2	-0.15	-0.11	-0.17
		T1	-0.42	-0.46	-0.53
		T2	-0.44	-0.45	-0.44

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-6. CHARGING PROPENSITY OF MATERIAL 2 IN nC. INCLINE PLANE @ 10 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
2	1	Q	0.06	0.05	0.02
		B1	0.11	0.13	0.17
		B2	0.03	-0.04	0.03
		T1	-0.35	-0.34	-0.48
		T2	-0.46	-0.61	-0.51
			roll 1	roll 2	roll 3
	2	Q	-0.07	-0.02	-0.04
		B1	0.04	0.04	0.04
		B2	-0.06	-0.04	0.00
		T1	-0.44	-0.58	-0.41
		T2	-0.44	-0.39	-0.46
			roll 1	roll 2	roll 3
	3	Q	-0.14	-0.17	-0.11
		B1	0.03	0.00	-0.03
		B2	-0.04	-0.04	-0.05
		T1	-0.42	-0.30	-0.35
		T2	-0.44	-0.46	-0.42
			roll 1	roll 2	roll 3
	4	Q	0.02	0.00	0.05
		B1	-0.07	0.04	0.00
		B2	-0.08	-0.06	-0.10
		T1	-0.44	-0.37	-0.44
		T2	-0.51	-0.59	-0.44
			roll 1	roll 2	roll 3
	5	Q	-0.06	-0.09	0.02
		B1	0.06	0.08	0.02
		B2	-0.04	-0.05	-0.05
		T1	-0.45	-0.43	-0.44
		T2	-0.41	-0.52	-0.50
			roll 1	roll 2	roll 3
	6	Q	0.07	0.07	0.06
		B1	-0.04	-0.07	-0.07
		B2	-0.11	-0.07	-0.13
		T1	-0.52	-0.50	-0.49
		T2	-0.48	-0.48	-0.59

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-7. CHARGING PROPENSITY OF MATERIAL 2 IN nC. INCLINE PLANE @ 15 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
2	1	Q	0.08	0.06	0.03
		B1	0.17	0.15	0.17
		B2	0.05	0.03	0.06
		T1	-0.49	-0.37	-0.41
		T2	-0.43	-0.47	-0.44
			roll 1	roll 2	roll 3
	2	Q	0.03	0.04	-0.07
		B1	0.13	0.07	0.06
		B2	-0.04	-0.06	-0.03
		T1	-0.37	-0.52	-0.46
		T2	-0.40	-0.52	-0.40
			roll 1	roll 2	roll 3
	3	Q	-0.03	-0.09	-0.04
		B1	0.03	0.04	0.00
		B2	-0.05	-0.05	-0.02
		T1	-0.40	-0.31	-0.38
		T2	-0.47	-0.39	-0.34
			roll 1	roll 2	roll 3
	4	Q	-0.03	0.05	0.09
		B1	0.04	0.01	0.10
		B2	-0.03	-0.03	-0.07
		T1	-0.39	-0.43	-0.56
		T2	-0.40	-0.59	-0.64
			roll 1	roll 2	roll 3
	5	Q	0.01	0.03	-0.04
		B1	0.15	0.11	0.13
		B2	-0.02	-0.03	0.01
		T1	-0.35	-0.43	-0.34
		T2	-0.42	-0.58	-0.44
			roll 1	roll 2	roll 3
	6	Q	0.04	0.07	0.06
		B1	0.05	0.11	0.03
		B2	-0.05	-0.02	-0.07
		T1	-0.47	-0.63	-0.57
		T2	-0.54	-0.48	-0.42

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-8. CHARGING PROPENSITY OF MATERIAL 2 IN nC. INCLINE PLANE @ 20 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
2	1	Q	0.08	0.11	0.12
		B1	0.06	0.10	0.09
		B2	0.04	0.05	-0.02
		T1	-0.29	-0.49	-0.35
		T2	-0.37	-0.42	-0.48
			roll 1	roll 2	roll 3
	2	Q	0.12	0.10	0.11
		B1	0.15	0.07	0.06
		B2	0.04	0.00	0.02
		T1	-0.37	-0.40	-0.37
		T2	-0.42	-0.37	-0.37
			roll 1	roll 2	roll 3
	3	Q	0.10	0.08	0.11
		B1	0.08	0.15	0.11
		B2	-0.05	-0.03	0.05
		T1	-0.77	-0.49	-0.43
		T2	-0.44	-0.49	-0.40
			roll 1	roll 2	roll 3
	4	Q	0.11	0.13	0.13
		B1	0.12	0.06	0.09
		B2	-0.01	0.00	-0.03
		T1	-0.48	-0.44	-0.38
		T2	-0.41	-0.44	-0.52
			roll 1	roll 2	roll 3
	5	Q	0.09	0.12	0.08
		B1	0.08	0.08	0.14
		B2	-0.03	-0.03	0.01
		T1	-0.47	-0.42	-0.36
		T2	-0.42	-0.41	-0.40
			roll 1	roll 2	roll 3
	6	Q	0.08	0.11	0.11
		B1	0.05	0.07	0.11
		B2	0.05	-0.06	-0.02
		T1	-0.46	-0.39	-0.47
		T2	-0.39	-0.43	-0.38

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-9. CHARGING PROPENSITY OF MATERIAL 3 IN nC. INCLINE PLANE @ 5 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
3	1	Q	0.04	0.13	0.17
		B1	0.48	0.45	0.43
		B2	0.17	0.12	0.06
		T1	-0.39	-0.54	-0.48
		T2	-0.39	-0.42	-0.40
			roll 1	roll 2	roll 3
	2	Q	0.20	0.14	0.17
		B1	0.36	0.57	0.50
		B2	0.14	0.10	0.12
		T1	-0.38	-0.42	-0.55
		T2	-0.39	-0.37	-0.45
			roll 1	roll 2	roll 3
	3	Q	0.27	0.25	0.12
		B1	0.55	0.48	0.45
		B2	0.11	0.16	0.09
		T1	-0.38	-0.36	-0.39
		T2	-0.30	-0.24	-0.32
			roll 1	roll 2	roll 3
	4	Q	0.40	0.23	0.20
		B1	0.59	0.68	0.58
		B2	0.23	0.11	0.07
		T1	-0.46	-0.49	-0.41
		T2	-0.43	-0.28	-0.34
			roll 1	roll 2	roll 3
	5	Q	0.20	0.22	0.32
		B1	0.66	0.49	0.47
		B2	0.06	0.01	0.09
		T1	-0.39	-0.43	-0.43
		T2	-0.46	-0.37	-0.54
			roll 1	roll 2	roll 3
	6	Q	0.17	0.22	0.28
		B1	0.45	0.39	0.27
		B2	-0.05	-0.05	-0.08
		T1	-0.35	-0.39	-0.40
		T2	-0.43	-0.42	-0.36

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-10. CHARGING PROPENSITY OF MATERIAL 3 IN nC. INCLINE PLANE @ 10 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
3	1	Q	0.04	0.20	0.21
		B1	0.45	0.45	0.33
		B2	0.13	0.09	0.08
		T1	-0.37	-0.41	-0.47
		T2	-0.54	-0.47	-0.44
			roll 1	roll 2	roll 3
	2	Q	0.28	0.18	0.16
		B1	0.41	0.44	0.47
		B2	0.08	0.11	0.09
		T1	-0.36	-0.41	-0.38
		T2	-0.41	-0.45	-0.48
			roll 1	roll 2	roll 3
	3	Q	0.29	0.31	0.12
		B1	0.51	0.34	0.35
		B2	0.12	0.20	0.11
		T1	-0.59	-0.43	-0.33
		T2	-0.34	-0.41	-0.47
			roll 1	roll 2	roll 3
	4	Q	0.45	0.26	0.24
		B1	0.48	0.53	0.52
		B2	0.19	0.09	0.07
		T1	-0.47	-0.44	-0.47
		T2	-0.58	-0.43	-0.35
			roll 1	roll 2	roll 3
	5	Q	0.20	0.24	0.34
		B1	0.61	0.38	0.43
		B2	-0.03	0.03	0.09
		T1	-0.40	-0.39	-0.46
		T2	-0.45	-0.45	-0.48
			roll 1	roll 2	roll 3
	6	Q	0.21	0.20	0.34
		B1	0.44	0.36	0.20
		B2	0.10	-0.11	0.02
		T1	-0.39	-0.41	-0.37
		T2	-0.45	-0.52	-0.53

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-11. CHARGING PROPENSITY OF MATERIAL 3 IN nC. INCLINE PLANE @ 15 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
3	1	Q	0.03	0.15	0.18
		B1	0.38	0.33	0.26
		B2	0.08	0.09	0.09
		T1	-0.42	-0.38	-0.37
		T2	-0.43	-0.44	-0.43
			roll 1	roll 2	roll 3
	2	Q	0.16	0.11	0.16
		B1	0.39	0.38	0.37
		B2	0.10	0.14	0.13
		T1	-0.39	-0.45	-0.41
		T2	-0.41	-0.43	-0.34
			roll 1	roll 2	roll 3
	3	Q	0.23	0.29	0.06
		B1	0.51	0.26	0.44
		B2	0.16	0.14	0.05
		T1	-0.46	-0.44	-0.38
		T2	-0.35	-0.31	-0.39
			roll 1	roll 2	roll 3
	4	Q	0.39	0.17	0.15
		B1	0.43	0.51	0.36
		B2	0.20	0.07	0.08
		T1	-0.45	-0.41	-0.33
		T2	-0.42	-0.43	-0.39
			roll 1	roll 2	roll 3
	5	Q	0.19	0.26	0.27
		B1	0.47	0.42	0.32
		B2	0.08	0.05	0.01
		T1	-0.44	-0.48	-0.51
		T2	-0.42	-0.45	-0.48
			roll 1	roll 2	roll 3
	6	Q	0.35	0.26	0.38
		B1	0.58	0.36	0.38
		B2	0.20	-0.16	0.10
		T1	-0.32	-0.42	-0.46
		T2	-0.62	-0.58	-0.52

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-12. CHARGING PROPENSITY OF MATERIAL 3 IN nC. INCLINE PLANE @ 20 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
3	1	Q	0.41	0.48	0.43
		B1	0.15	0.35	0.47
		B2	0.25	-0.15	0.16
		T1	-0.36	-0.29	-0.35
		T2	-0.41	-0.38	-0.34
			roll 1	roll 2	roll 3
	2	Q	0.49	0.37	0.48
		B1	0.44	0.67	0.68
		B2	0.17	0.15	0.11
		T1	-0.37	-0.31	-0.28
		T2	-0.40	-0.38	-0.38
			roll 1	roll 2	roll 3
	3	Q	0.46	0.58	0.47
		B1	0.88	0.78	0.77
		B2	0.11	0.13	0.05
		T1	-0.46	-0.37	-0.31
		T2	-0.32	-0.28	-0.32
			roll 1	roll 2	roll 3
	4	Q	0.50	0.40	0.52
		B1	0.70	0.73	0.89
		B2	0.26	0.24	0.25
		T1	-0.36	-0.36	-0.44
		T2	-0.36	-0.27	-0.39
			roll 1	roll 2	roll 3
	5	Q	0.40	0.44	0.44
		B1	0.85	0.80	0.91
		B2	0.18	0.16	0.18
		T1	-0.29	-0.38	-0.40
		T2	-0.26	-0.36	-0.36
			roll 1	roll 2	roll 3
	6	Q	0.45	0.41	0.49
		B1	0.90	0.82	1.12
		B2	0.22	0.25	0.17
		T1	-0.34	-0.35	-0.35
		T2	-0.45	-0.30	-0.43

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-13. CHARGING PROPENSITY OF MATERIAL 4 IN nC. INCLINE PLANE @ 5 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
4	1	Q	0.06	0.08	0.11
		B1	-0.04	-0.04	-0.01
		B2	-0.03	-0.03	-0.03
		T1	-0.34	-0.30	-0.34
		T2	-0.40	-0.39	-0.29
			roll 1	roll 2	roll 3
	2	Q	0.20	0.06	0.29
		B1	-0.03	-0.03	-0.02
		B2	-0.07	-0.04	-0.04
		T1	-0.31	-0.45	-0.42
		T2	-0.29	-0.33	-0.42
			roll 1	roll 2	roll 3
	3	Q	0.10	0.06	0.15
		B1	-0.04	-0.04	-0.03
		B2	-0.03	-0.03	-0.03
		T1	-0.41	-0.45	-0.38
		T2	-0.44	-0.64	-0.53
			roll 1	roll 2	roll 3
	4	Q	0.17	0.15	0.09
		B1	-0.02	-0.03	-0.05
		B2	-0.04	-0.04	-0.03
		T1	-0.45	-0.41	-0.48
		T2	-0.31	-0.39	-0.35
			roll 1	roll 2	roll 3
	5	Q	0.21	0.11	0.15
		B1	-0.03	-0.04	-0.04
		B2	-0.03	-0.04	-0.04
		T1	-0.40	-0.58	-0.38
		T2	-0.36	-0.46	-0.46
			roll 1	roll 2	roll 3
	6	Q	0.19	0.12	0.16
		B1	-0.04	-0.04	-0.04
		B2	-0.03	-0.03	-0.03
		T1	-0.35	-0.35	-0.43
		T2	-0.33	-0.41	-0.39

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-14. CHARGING PROPENSITY OF MATERIAL 4 IN nC. INCLINE PLANE @ 10 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
4	1	Q	0.16	0.14	0.24
		B1	-0.12	-0.04	-0.03
		B2	-0.03	-0.02	-0.02
		T1	-0.45	-0.41	-0.30
		T2	-0.21	-0.47	-0.25
			roll 1	roll 2	roll 3
	2	Q	0.25	0.13	0.07
		B1	-0.05	-0.04	-0.03
		B2	-0.04	-0.04	-0.04
		T1	-0.34	-0.46	-0.34
		T2	-0.31	-0.42	-0.40
			roll 1	roll 2	roll 3
	3	Q	0.07	0.09	0.11
		B1	-0.03	-0.04	-0.03
		B2	-0.03	-0.03	-0.04
		T1	-0.35	-0.27	-0.47
		T2	-0.30	-0.48	-0.51
			roll 1	roll 2	roll 3
	4	Q	0.07	0.04	0.13
		B1	-0.03	-0.03	-0.03
		B2	-0.03	-0.03	-0.03
		T1	-0.34	-0.43	-0.45
		T2	-0.43	-0.47	-0.48
			roll 1	roll 2	roll 3
	5	Q	0.07	0.03	0.06
		B1	-0.03	-0.04	-0.03
		B2	-0.03	-0.04	-0.03
		T1	-0.57	-0.48	-0.45
		T2	-0.31	-0.65	-0.52
			roll 1	roll 2	roll 3
	6	Q	0.20	0.13	0.21
		B1	-0.04	-0.03	-0.03
		B2	-0.03	-0.04	-0.03
		T1	-0.35	-0.34	-0.45
		T2	-0.38	-0.39	-0.43

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-15.

Mat

Table A-15. CHARGING PROPENSITY OF MATERIAL 4 IN nC. INCLINE PLANE @ 15 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
4	1	Q	0.05	0.13	0.02
		B1	-0.03	-0.02	-0.03
		B2	-0.04	-0.03	-0.02
		T1	-0.56	-0.48	-0.66
		T2	-0.32	-0.46	-0.36
			roll 1	roll 2	roll 3
	2	Q	0.20	0.13	0.03
		B1	-0.04	-0.03	-0.05
		B2	-0.03	-0.04	-0.03
		T1	-0.36	-0.30	-0.46
		T2	-0.32	-0.38	-0.37
			roll 1	roll 2	roll 3
	3	Q	0.04	0.06	0.12
		B1	-0.03	-0.03	-0.04
		B2	-0.03	-0.03	-0.03
		T1	-0.57	-0.48	-0.31
		T2	-0.43	-0.44	-0.52
			roll 1	roll 2	roll 3
	4	Q	0.10	0.02	0.12
		B1	-0.04	-0.04	-0.04
		B2	-0.03	-0.04	-0.04
		T1	-0.46	-0.49	-0.37
		T2	-0.69	-0.49	-0.55
			roll 1	roll 2	roll 3
	5	Q	0.01	0.05	0.04
		B1	-0.05	-0.04	-0.04
		B2	-0.03	-0.04	-0.04
		T1	-0.43	-0.61	-0.63
		T2	-0.28	-0.65	-0.43
			roll 1	roll 2	roll 3
	6	Q	0.22	0.09	0.09
		B1	-0.03	-0.03	-0.03
		B2	-0.03	-0.02	-0.03
		T1	-0.38	-0.34	-0.45
		T2	-0.37	-0.53	-0.49

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-16. CHARGING PROPENSITY OF MATERIAL 4 IN nC. INCLINE PLANE @ 20 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
4	1	Q	0.07	0.03	0.03
		B1	0.00	0.02	0.01
		B2	-0.03	0.01	0.01
		T1	-0.39	-0.33	-0.40
		T2	-0.35	-0.30	-0.33
			roll 1	roll 2	roll 3
	2	Q	0.06	0.06	0.04
		B1	0.00	-0.02	0.00
		B2	-0.02	0.00	0.02
		T1	-0.34	-0.35	-0.47
		T2	-0.40	-0.38	-0.36
			roll 1	roll 2	roll 3
	3	Q	0.04	0.04	0.07
		B1	0.02	0.00	0.02
		B2	0.01	0.02	0.01
		T1	-0.34	-0.36	-0.39
		T2	-0.42	-0.43	-0.38
			roll 1	roll 2	roll 3
	4	Q	0.03	0.05	0.05
		B1	0.00	0.01	0.01
		B2	0.01	0.01	0.01
		T1	-0.37	-0.39	-0.37
		T2	-0.35	-0.39	-0.35
			roll 1	roll 2	roll 3
	5	Q	0.04	0.03	0.03
		B1	0.01	0.01	0.02
		B2	0.02	0.01	0.01
		T1	-0.35	-0.38	-0.37
		T2	-0.27	-0.47	-0.43
			roll 1	roll 2	roll 3
	6	Q	0.03	0.03	-0.05
		B1	0.02	0.02	0.02
		B2	0.00	0.01	0.01
		T1	-0.47	-0.41	-0.42
		T2	-0.41	-0.46	-0.46

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-17. CHARGING PROPENSITY OF MATERIAL 5 IN nC. INCLINE PLANE @ 5 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
5	1	Q	0.38	0.28	0.35
		B1	-0.03	-0.03	-0.02
		B2	-0.02	-0.02	-0.03
		T1	-0.38	-0.41	-0.42
		T2	-0.49	-0.53	-0.52
			roll 1	roll 2	roll 3
	2	Q	0.30	0.48	0.30
		B1	-0.03	-0.03	-0.03
		B2	-0.03	-0.03	-0.03
		T1	-0.46	-0.45	-0.41
		T2	-0.50	-0.48	-0.44
			roll 1	roll 2	roll 3
	3	Q	0.33	0.30	0.30
		B1	-0.05	-0.03	-0.04
		B2	-0.03	-0.04	-0.03
		T1	-0.50	-0.47	-0.43
		T2	-0.55	-0.44	-0.62
			roll 1	roll 2	roll 3
	4	Q	0.21	0.40	0.26
		B1	-0.04	-0.04	-0.05
		B2	-0.04	-0.03	-0.05
		T1	-0.32	-0.36	-0.42
		T2	-0.39	-0.44	-0.45
			roll 1	roll 2	roll 3
	5	Q	0.36	0.38	0.54
		B1	-0.04	-0.04	-0.04
		B2	-0.03	-0.03	-0.03
		T1	-0.49	-0.46	-0.44
		T2	-0.37	-0.45	-0.48
			roll 1	roll 2	roll 3
	6	Q	0.40	0.39	0.34
		B1	-0.04	-0.05	-0.04
		B2	-0.04	-0.03	-0.04
		T1	-0.37	-0.42	-0.45
		T2	-0.47	-0.48	-0.47

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-18. CHARGING PROPENSITY OF MATERIAL 5 IN nC. INCLINE PLANE @ 10 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
5	1	Q	0.45	0.33	0.42
		B1	-0.04	-0.03	-0.04
		B2	-0.03	-0.03	-0.03
		T1	-0.53	-0.51	-0.43
		T2	-0.52	-0.50	-0.50
			roll 1	roll 2	roll 3
	2	Q	0.31	0.26	0.30
		B1	-0.03	-0.05	-0.04
		B2	-0.03	-0.04	-0.04
		T1	-0.43	-0.37	-0.40
		T2	-0.47	-0.49	-0.47
			roll 1	roll 2	roll 3
	3	Q	0.31	0.24	0.24
		B1	-0.03	-0.03	-0.03
		B2	-0.04	-0.04	-0.03
		T1	-0.42	-0.50	-0.48
		T2	-0.51	-0.44	-0.48
			roll 1	roll 2	roll 3
	4	Q	0.15	0.27	0.16
		B1	-0.04	-0.04	-0.04
		B2	-0.04	-0.03	-0.03
		T1	-0.41	-0.39	-0.41
		T2	-0.53	-0.46	-0.49
			roll 1	roll 2	roll 3
	5	Q	0.36	0.40	0.37
		B1	-0.03	-0.04	-0.05
		B2	-0.03	-0.04	-0.03
		T1	-0.54	-0.44	-0.36
		T2	-0.38	-0.40	-0.49
			roll 1	roll 2	roll 3
	6	Q	0.31	0.25	0.27
		B1	-0.04	-0.04	-0.04
		B2	-0.03	-0.03	-0.04
		T1	-0.50	-0.49	-0.41
		T2	-0.43	-0.53	-0.46

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-19. CHARGING PROPENSITY OF MATERIAL 5 IN nC. INCLINE PLANE @ 15 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
5	1	Q	0.36	0.34	0.40
		B1	-0.04	-0.03	-0.03
		B2	-0.04	-0.03	-0.04
		T1	-0.57	-0.44	-0.42
		T2	-0.44	-0.51	-0.51
			roll 1	roll 2	roll 3
	2	Q	0.39	0.27	0.34
		B1	-0.03	-0.04	-0.03
		B2	-0.02	-0.03	-0.03
		T1	-0.45	-0.41	-0.46
		T2	-0.43	-0.46	-0.46
			roll 1	roll 2	roll 3
	3	Q	0.39	0.32	0.35
		B1	-0.04	-0.03	-0.03
		B2	-0.03	-0.03	-0.04
		T1	-0.49	-0.47	-0.46
		T2	-0.47	-0.47	-0.51
			roll 1	roll 2	roll 3
	4	Q	0.14	0.29	0.17
		B1	-0.03	-0.03	-0.03
		B2	-0.03	-0.03	-0.03
		T1	-0.43	-0.41	-0.47
		T2	-0.54	-0.48	-0.50
			roll 1	roll 2	roll 3
	5	Q	0.51	0.43	0.43
		B1	-0.04	-0.04	-0.03
		B2	-0.04	-0.03	-0.03
		T1	-0.56	-0.41	-0.45
		T2	-0.54	-0.39	-0.51
			roll 1	roll 2	roll 3
	6	Q	0.53	0.35	0.27
		B1	-0.03	-0.03	-0.01
		B2	-0.03	-0.03	-0.03
		T1	-0.39	-0.51	-0.48
		T2	-0.45	-0.46	-0.52

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-20. CHARGING PROPENSITY OF MATERIAL 5 IN nC. INCLINE PLANE @ 20 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
5	1	Q	0.34	0.30	0.34
		B1	0.00	-0.01	-0.01
		B2	-0.02	0.00	0.00
		T1	-0.33	-0.37	-0.52
		T2	-0.43	-0.46	-0.44
			roll 1	roll 2	roll 3
	2	Q	0.34	0.34	0.31
		B1	0.00	-0.01	0.01
		B2	-0.01	-0.03	0.00
		T1	-0.45	-0.48	-0.46
		T2	-0.38	-0.48	-0.46
			roll 1	roll 2	roll 3
	3	Q	0.31	0.31	0.31
		B1	-0.01	-0.01	-0.02
		B2	0.00	-0.02	0.00
		T1	-0.50	-0.45	-0.40
		T2	-0.44	-0.41	-0.38
			roll 1	roll 2	roll 3
	4	Q	0.30	0.29	0.34
		B1	-0.01	0.00	0.01
		B2	0.00	0.01	0.01
		T1	-0.37	-0.37	-0.48
		T2	-0.45	-0.41	-0.49
			roll 1	roll 2	roll 3
	5	Q	0.30	0.27	0.31
		B1	0.00	0.00	0.01
		B2	0.01	-0.01	-0.01
		T1	-0.41	-0.44	-0.41
		T2	-0.47	-0.48	-0.47
			roll 1	roll 2	roll 3
	6	Q	0.28	0.26	0.27
		B1	0.00	0.00	0.00
		B2	0.00	0.01	0.01
		T1	-0.43	-0.41	-0.40
		T2	-0.45	-0.40	-0.44

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-21. CHARGING PROPENSITY OF MATERIAL 6 IN nC. INCLINE PLANE @ 5 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
6	1	Q	0.12	0.11	0.17
		B1	0.13	-0.08	-0.23
		B2	0.05	-0.04	-0.15
		T1	-0.28	-0.35	-0.35
		T2	-0.33	-0.39	-0.44
			roll 1	roll 2	roll 3
	2	Q	0.28	0.31	0.39
		B1	0.17	-0.13	-0.52
		B2	-0.06	0.05	-0.06
		T1	-0.26	-0.29	-0.43
		T2	-0.34	-0.35	-0.29
			roll 1	roll 2	roll 3
	3	Q	-0.06	0.07	0.09
		B1	0.14	0.05	0.17
		B2	-0.04	-0.10	-0.04
		T1	-0.45	-0.43	-0.44
		T2	-0.62	-0.56	-0.57
			roll 1	roll 2	roll 3
	4	Q	0.06	0.03	0.14
		B1	-0.15	-0.13	0.02
		B2	-0.05	-0.11	-0.08
		T1	-0.29	-0.45	-0.50
		T2	-0.58	-0.55	-0.43
			roll 1	roll 2	roll 3
	5	Q	0.06	0.15	0.15
		B1	0.16	0.18	0.14
		B2	-0.02	0.07	0.02
		T1	-0.37	-0.38	-0.33
		T2	-0.48	-0.60	-0.46
			roll 1	roll 2	roll 3
	6	Q	0.11	0.11	0.18
		B1	-0.05	-0.06	0.01
		B2	-0.13	-0.19	-0.17
		T1	-0.31	-0.34	-0.33
		T2	-0.29	-0.39	-0.42

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-22. CHARGING PROPENSITY OF MATERIAL 6 IN nC. INCLINE PLANE @ 10 DEGREES

Material	Sample	Cylinders			
			roll 1	roll 2	roll 3
6	1	Q	0.10	0.11	0.19
		B1	0.12	-0.19	-0.33
		B2	-0.16	-0.05	-0.13
		T1	-0.29	-0.31	-0.37
		T2	-0.31	-0.30	-0.38
			roll 1	roll 2	roll 3
	2	Q	0.26	0.33	0.37
		B1	-0.10	-0.19	-0.56
		B2	-0.06	-0.07	-0.14
		T1	-0.34	-0.25	-0.38
		T2	-0.41	-0.32	-0.35
			roll 1	roll 2	roll 3
	3	Q	0.04	0.06	0.09
		B1	0.13	-0.01	0.09
		B2	-0.10	-0.09	-0.09
		T1	-0.66	-0.49	-0.49
		T2	-0.55	-0.57	-0.54
			roll 1	roll 2	roll 3
	4	Q	0.08	-0.04	0.12
		B1	-0.17	-0.17	-0.05
		B2	-0.05	-0.15	-0.02
		T1	-0.32	-0.48	-0.53
		T2	-0.46	-0.59	-0.44
			roll 1	roll 2	roll 3
	5	Q	0.10	0.19	0.23
		B1	0.09	0.13	0.16
		B2	-0.06	-0.03	-0.02
		T1	-0.28	-0.49	-0.38
		T2	-0.35	-0.35	-0.45
			roll 1	roll 2	roll 3
	6	Q	0.13	0.13	0.16
		B1	-0.09	-0.07	-0.03
		B2	-0.19	-0.18	-0.14
		T1	-0.38	-0.36	-0.33
		T2	-0.46	-0.55	-0.53

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-23. CHARGING PROPENSITY OF MATERIAL 6 IN nC. INCLINE PLANE @ 15 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
6	1	Q	0.12	0.15	0.20
		B1	0.02	-0.13	-0.43
		B2	-0.22	-0.17	-0.12
		T1	-0.27	-0.40	-0.38
		T2	-0.32	-0.27	-0.41
			roll 1	roll 2	roll 3
	2	Q	0.22	0.21	0.26
		B1	-0.07	-0.23	-0.42
		B2	-0.08	0.04	-0.06
		T1	-0.36	-0.30	-0.40
		T2	-0.35	-0.39	-0.32
			roll 1	roll 2	roll 3
	3	Q	0.05	0.14	0.10
		B1	0.04	-0.04	-0.04
		B2	-0.09	-0.12	-0.17
		T1	-0.44	-0.44	-0.51
		T2	-0.53	-0.54	-0.47
			roll 1	roll 2	roll 3
	4	Q	0.08	-0.05	0.07
		B1	-0.13	-0.13	-0.19
		B2	-0.09	-0.05	-0.09
		T1	-0.33	-0.44	-0.44
		T2	-0.52	-0.50	-0.50
			roll 1	roll 2	roll 3
	5	Q	0.08	0.27	0.19
		B1	0.15	0.17	0.10
		B2	-0.04	-0.05	0.01
		T1	-0.28	-0.35	-0.46
		T2	-0.75	-0.45	-0.53
			roll 1	roll 2	roll 3
	6	Q	0.13	0.13	0.18
		B1	-0.06	-0.10	-0.03
		B2	-0.09	-0.03	-0.09
		T1	-0.90	-0.40	-0.51
		T2	-0.76	-0.57	-0.59

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

Table A-24. CHARGING PROPENSITY OF MATERIAL 6 IN nC. INCLINE PLANE @ 20 DEGREES

Material	Sample		Cylinders		
			roll 1	roll 2	roll 3
6	1	Q	0.09	0.06	0.05
		B1	-0.16	-0.17	-0.19
		B2	-0.11	-0.08	-0.06
		T1	-0.67	-0.46	-0.51
		T2	-0.61	-0.41	-0.56
			roll 1	roll 2	roll 3
	2	Q	0.04	0.06	0.04
		B1	-0.11	-0.07	0.00
		B2	-0.10	-0.07	-0.08
		T1	-0.43	-0.71	-0.60
		T2	-0.53	-0.51	-0.58
			roll 1	roll 2	roll 3
	3	Q	0.05	0.05	0.04
		B1	0.03	0.03	0.03
		B2	-0.07	-0.12	-0.05
		T1	-0.52	-0.51	-0.56
		T2	-0.55	-0.52	-0.51
			roll 1	roll 2	roll 3
	4	Q	0.07	0.07	0.09
		B1	0.02	-0.06	0.00
		B2	-0.06	-0.07	-0.07
		T1	-0.46	-0.51	-0.54
		T2	-0.49	-0.49	-0.55
			roll 1	roll 2	roll 3
	5	Q	0.07	0.09	0.10
		B1	0.06	0.00	-0.03
		B2	-0.06	-0.09	-0.08
		T1	-0.62	-0.52	-0.59
		T2	-0.53	-0.52	-0.70
			roll 1	roll 2	roll 3
	6	Q	0.09	0.13	0.10
		B1	0.10	0.14	0.07
		B2	-0.10	-0.11	-0.07
		T1	-0.62	-0.51	-0.58
		T2	-0.49	-1.05	-0.56

Q - Quartz
B1 & B2 - Brass
T1 & T2 - Teflon

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