Electrostatic Charge Acceptance and Decay of Powder Coating Particles

G. DALE CHEEVER, *General Motors Research Laboratories, Warren, Michigan 48090*

Synopsis

Techniques have been developed to measure the acceptance and decay of electro-static charge on a wide variety of powder coatings. The measurement of the initial charge carried by the powder was affected by the amount of powder deposited. The decay of charge occurred within four time scales: (1) 1 sec, electron loss to air and to the metallic substrate; (2) 1 to 5 sec, electron flow to neutralize induced positive charge; (3) 5 to 100 sec, rapid decay from powder; and (4) 1,000 to 10,000 sec, very long term decay. Since the decay of charge was markedly affected by moisture and composition, the decay properties can be controlled by these parameters. A mathematical model was constructed describing the quantitative charge decay during the time period of 100 to 10,000 sec. There was considerable heterogeneity within the powders with regard to charge acceptance and interaction with moisture. These measurement techniques give information concerning electrostatic effects on particle transport, adhesion, and polymer electrostatic behavior which are very important variables in a powder coating process.

INTRODUCTION

During the last ten years, considerable interest has been shown by the paint industry in the use of powdered polymers as a surface coating. Advantages of powder coatings described by Joyce[1] include reduction or elimination of paint solvent emissions from spray booths and ovens, less use of natural gas, and elimination of paint sludge. A survey of the state of the art of powder coatings has been reported by Levinson.[2]

A study of the acquisition and decay of electrostatic charge is particularly important because the charge is the mechanism by which the powder particles are conducted to the part to be coated. Also, the presence of charge on the coated part plays a vital role in the adhesion of the coating to the part during handling. A number of publications have appeared where studies have been made in electrostatic phenomena. Spiller[3] reported experiments in the charging and discharging characteristics of powdered polymers. Zabel and Estcourt[4] measured the charge response of powders exposed to ion bombardment. Oesterle and Szasz[5] and Szasz[6] give some of the characteristics of electrostatic powder spraying. White[7] and Pomeraniec, Shapiro, and Mark[8] discuss the basic factors involved in electrostatic charging.
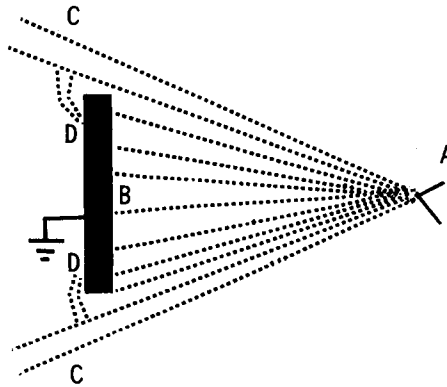
Fig. 1. Schematic representation of the present electrostatic powder coating process.

The present paper deals with techniques for measuring the electrostatic charge on powder coatings quickly and their role in a powder coating process.

EXPERIMENTAL

Powder Coating Process

A schematic representation of the present electrostatic powder coating process is shown in Figure 1. The powder is fluidized with air and fed to the electrostatic spray gun at a feed rate of approximately 7 oz/min (3.3 g/sec). The powder is charged with 60 kilovolts and 125 μamp. The gun is a hand-held Ransburg Model 322 AC with a Ransburg Model 231 power supply. The rate of air flow in the booth was 80 ft/min (0.40 m/sec). The distance of the gun to the target was 6 in. (15 cm). Some of the powder is collected on the front of the grounded part (B), some misses the part completely (C), and a very small amount deposits on the back (D). This effect is called powder wrap-around. The coated part is baked at temperatures of 325–450°F for 5 to 30 min. Baking fuses the coating into a continuous film.

Initial Average Charge per Particle

White[7] derived an expression for the theoretical limiting charge acquired by a dielectric particle under ion bombardment:

$$n_s = \frac{3\epsilon}{(\epsilon + 2)} E_0 a^2 \tag{1}$$

where n_s = limiting or saturation charge, ϵ = dielectric constant, E_0 = electric field strength, and a = particle radius.

In attempting to measure the initial charge carried by powder particles, a complication was introduced by the relatively large amount of charge carried by the fluidizing air. In order to measure the charge on the powder
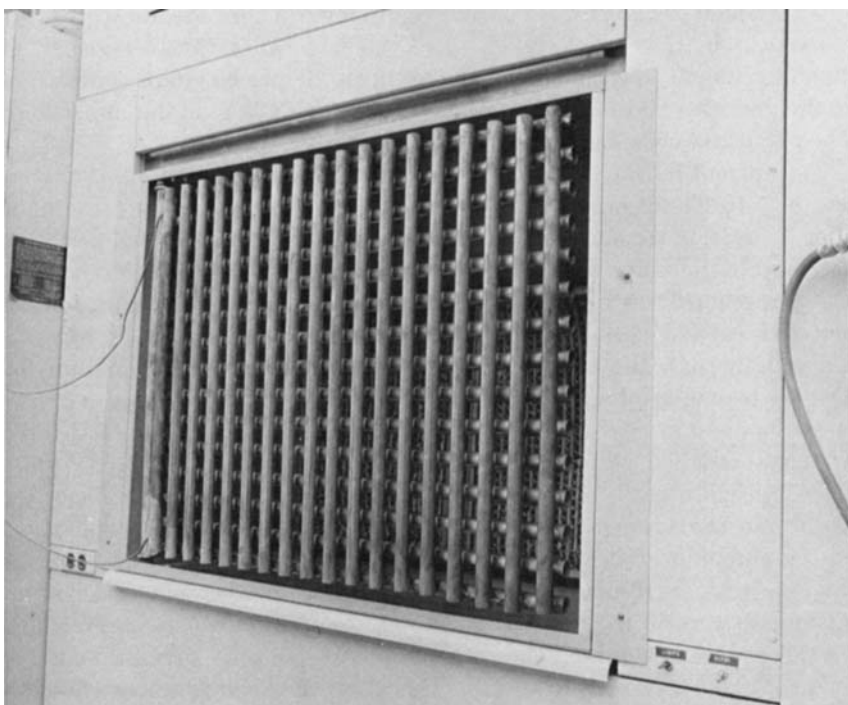
Fig. 2. Photograph of grounded copper barrier in front of powder spray booth.

coating particles only, it was necessary to remove the charged air. This was accomplished by building a copper barrier in front of the powder coating spray booth. This grounded barrier (Fig. 2) was constructed of 1-in. copper tubing, silver soldered into a grid 1-in. apart. When an 18- by 24-in. (46- by 61-cm) piece of aluminum foil was sprayed with charged air only, the current was 4×10^{-6} amp. The current and coulombs flowing from the aluminum foil were measured with a Keithley 610C electrometer and recorded on a Honeywell 906C Visicorder optical oscillograph. With the intervening copper screen and spraying 6 in. (15 cm) in front of the screen, the current measured dropped to 2×10^{-8} amp. The target was located 6 in. (15 cm) behind the copper screen. Thus, the grounded copper screen effectively removes most of the charged air.

The mechanism of the removal of the charged air is that the air ions are very small and move quickly to be discharged on the grounded copper. Of course, much powder was also deposited on the copper tubing but enough passes through the copper screen to make measurements. Since the holes in the screen are 1 in.^{2}, or approximately 6 cm^2, in area and the particles are only approximately 10^{-5} cm^2 in area, there are sufficient particles passing through the screen to give a true representation of the impinging charged cloud. Also, particle size distribution analyses of the powder deposited through the copper screen onto the aluminum substrate

was the same as the powder prior to spraying. There was no segregation of particles by the copper screen. In a typical powder, the average particle diameter was 21 μ, with 32% of the particles 10 μ or less in diameter, 64% of the particles 10 to 60 μ in diameter, and with 100 μ as the upper limit. The particles were spherical to elliposidal in shape.

The current flowing from the air plus powder passing through the screen was 1×10^{-7} amp, which is an order of magnitude higher than that of air alone. Most of the charged air was removed by the grounded copper screen and most of the charge was carried by the powder coating particles.

A preweighed 18- by 24-in. (46- by 61-cm) piece of aluminum foil was placed 6 in. (15 cm) behind the grounded copper screen. Powder was sprayed through the copper screen and collected on the aluminum foil. The electrometer integrated the current to give the total charge expressed in coulombs flowing from the aluminum foil. The aluminum foil target was again weighed, with the difference being the weight of deposited powder. This procedure gave, then, the coulombs per gram of powder deposited. To obtain the average charge per particle, the total number of particles on the aluminum foil were determined by counting the particles from ten random areas at 100$\times$ in a microscope. The number of particles in a given area was 50 to 100; therefore, 500 to 1000 particles were counted for these measurements. The total number of particles were estimated by integrating over the entire sheet. This gives the average initial coulombs per particle.

Initial Charge Decay

To study the decay of charge for the first 10 sec after deposition, the grounded copper screen was employed. Powder was sprayed through the copper screen onto the aluminum foil, and the current was 1×10^{-7} amp, as reported above. The powder was sprayed for 5 sec. Then, the gun was turned off and placed in a grounded can next to the spray booth. This grounded can ensured that there was no detection of charge from the gun and the power supply. Next, the current flowing from the powder was measured as a function of time and recorded.

Long-Term Charge Decay

The voltage developed by the charge retained on the particles after 10 sec was measured with a Keithley 2501 static detector head. This detector is well shielded and has excellent stability. It is a capacitance probe with known capacitance so that the charge which develops the voltage can be calculated.

Immediately after deposition, the coating on 4- by 4-in. zinc phosphated steel panels was transferred and placed on a grounded aluminum plate. The static head was positioned exactly $3/8$ in. (0.95 cm) above the surface of the coating. The voltage developed was measured as a function of time. The measurement required approximately 1 sec. The panel was removed from beneath the static detector and left on the grounded plate. The
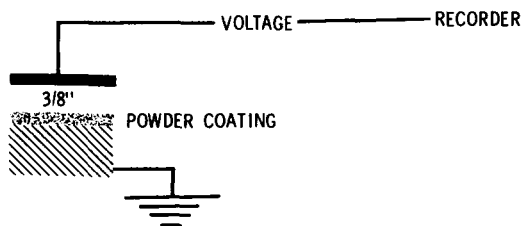
Fig. 3. Measurement of long-term electrostatic charge.

static head then was grounded. After 20 to 100 sec, the charged panel was returned to the measuring position. A total of 10 to 20 readings were taken over a time period of 700 sec. The measurement technique is shown schematically in Figure 3.

In addition to measuring the voltage of deposited panels, coatings which had lost their charge or coatings applied with a doctor blade from a hexane dispersion were charged 10 sec with the electrostatic gun at 60 kV and 6-in. gun distance. Their charge decays were measured similarly.

Voltage decay was studied as a function of relative humidity in a Tenney Mite 5 environmental cabinet. The coated panels were placed in the Tenney at 25%, 45%, 60%, and 80% relative humidities at 75°F for periods of time long enough to assure equilibrium. The 2501 detection head was also placed in the Tenney. For electrostatic charging, the panels were removed from the Tenney, charged in air 10 sec with 60 kV at 6 in. gun distance, and returned to the Tenney for measurement. This process occurs so rapidly that the sample water equilibrium probably is not disturbed by the step. It was not possible to measure the voltage at 100% relative humidity because of water condensation on the samples and the charge detection probe.

RESULTS AND DISCUSSION

Initial Charge per Particle

The Viscorder tracing of the coulomb yield as a function of time for charged air only sprayed through the copper screen onto aluminum foil is given in Figure 4. The yield rises to 0.88×10^{-7} coulombs and then remains constant at this value indefinitely.

A tracing from the Visicorder is given in Figure 5 of the coulomb yield as a function of time for the No. 1 Red Cellulose Acetate Butyrate (CAB) powder. It is seen that the coulomb yield rises rapidly to 0.94×10^{-6} coulombs, then drops to 0.82×10^{-6} coulombs. This behavior was seen with all the powders. The coulomb yield was taken as the highest value reached, namely, 0.94×10^{-6} colulombs for the No. 1 Red CAB powder, for all the powders.

The charge carried by the No. 2 White Thermoplastic Acrylic Powder coating as a function of the amount of powder deposited is given in Figure 6.
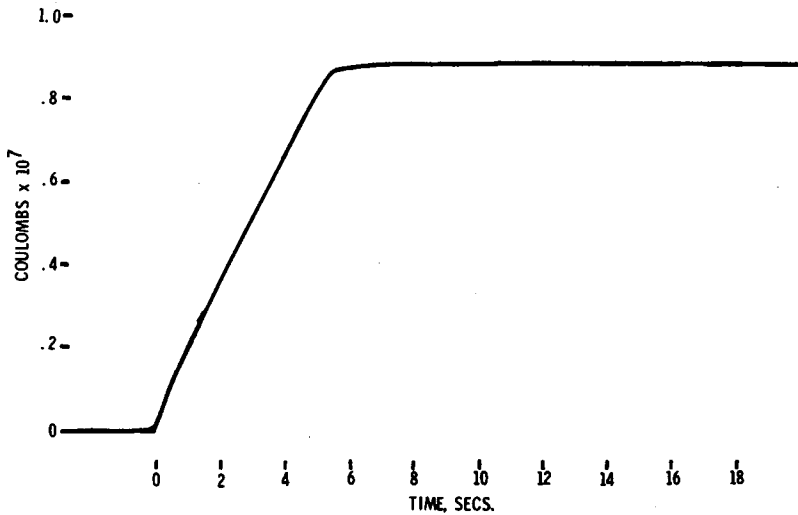
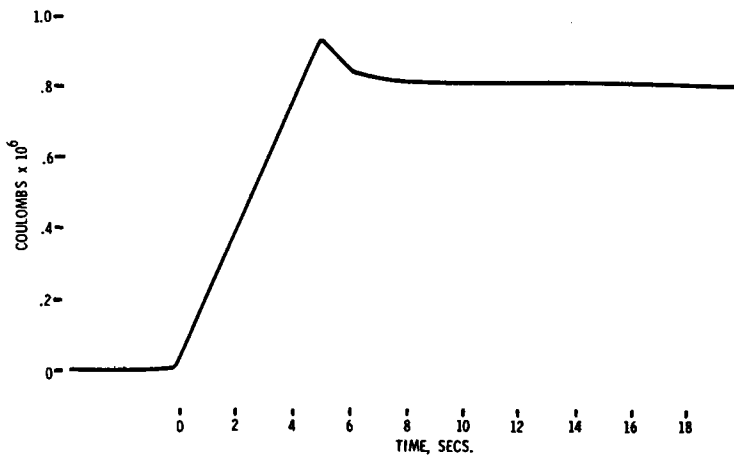Fig. 4. Coulomb yield as a function of time for charged air only.

Fig. 5. Coulomb yield as a function of time for the No. 1 Red Cellulose Acetate Butyrate powder.

Initial Decay Period

The current flowing from the aluminum foil as a function of time is given in Figure 7 for the No. 2 White Thermoplastic Acrylic powder. Time zero was taken as 0.1 sec before the gun was removed. Also, given on the graph is the integration of the current curve below the zero axis. The decay of current without the copper screen was the same, except that the initial current was 10^{-5} amp instead of 10^{-7} amp.

A summary of the coulombs per gram for a number of powders is given in Table I. Also given are the amounts of powder deposited and the drop in coulombs from the maximum value. The coulombs per gram were of

TABLE I
Charge Carried by Powders at 60 Negative Kilovolts

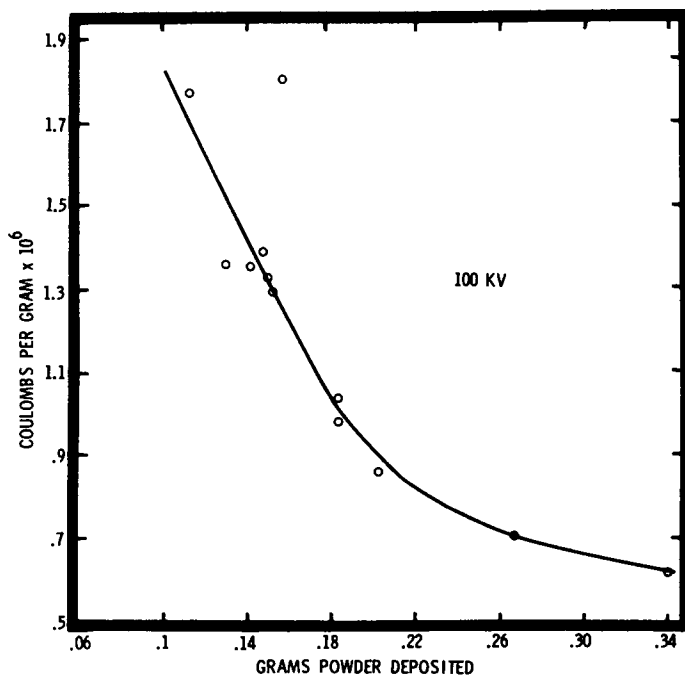|	Powder	Amount deposited, g	Coulombs per gram $\times 10^7$	Positive coulombs $\times 10^7$
No. 1	Red Thermoplastic Acrylic	2.19	4.8	1.2
No. 2	White Thermoplastic Acrylic	2.02	4.2	1.0
No. 5	White Thermoplastic Acrylic	2.22	5.0	0.9
No. 1	White Thermoset Acrylic	2.20	4.1	1.1
No. 1	Red CAB	1.91	4.9	1.1
No. 2	White CAB	2.03	4.3	0.9
No. 1	Blue Epoxy	2.04	4.9	1.4
No. 1	Unpigmented Polyethylene	1.91	4.7	1.7
No. 1	Orange Polyterphthalate	2.29	4.3	0.8
No. 1	Unpigmented Polypropylene	2.22	4.2	0.8
No. 1	Green Vinyl	2.64	2.4	0.4
No. 1	Unpigmented Nylon 11	1.65	5.0	0.3

Fig. 6. Coulombs per gram of No. 2 White Thermoplastic Acrylic powder coating as a function of amount of powder deposited.

negative polarity, and the drop in coulombs were of positive polarity, as shown by Figure 7. In general, the more conductive the powder, the smaller is the induced positive charge which is reasonable. High conductivity would permit rapid neutralization of positive charge.

When the aluminum foil was sprayed with charged air only (Fig. 4), the drop in coulombs from the maximum value shown in Figure 5 was not
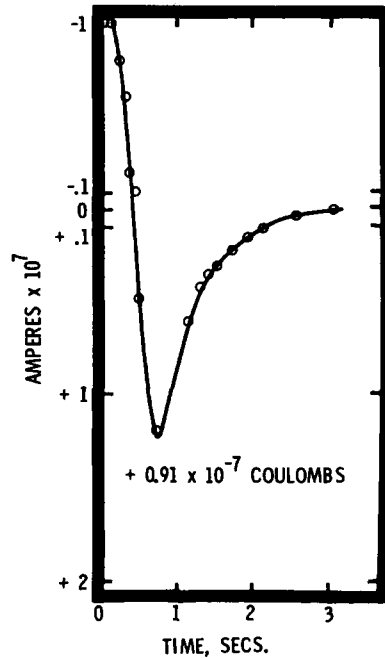
Fig. 7. Current as a function of time for the No. 2 White Thermoplastic powder.

observed. The drop in coulombs was seen only with the powders; there-
fore, this phenomena is a function of the powders and is not some electronic
anomaly. The Keithley electrometer in the coulomb measurement mode
measures the voltage developed across a capacitor which is being charged
by the incoming current.[9] As the powder was being sprayed, negative
current decayed from the powder flowed to the aluminum foil onto the
capacitor in the Keithley electrometer. When the gun was removed, nega-
tive charge flowed out of the capacitor back to the aluminum foil. This
gave a drop in the charge on the capacitor and a drop in the number of
coulombs. This suggests that negative current was flowing back to the
powder to neutralize induced positive charge in the powder.

This same reversal of current was seen in the current decay curve of
Figure 7. As soon as the gun was removed, the negative current dropped
within 0.5 to 0.7 sec to zero and then proceeded to decay in the positive
direction. Comparing the integral of the positive current flow with the
coulomb drop in Table I shows that it is equal; therefore, there was dupli-
cation of this positive charge effect both qualitatively and quantitatively.

A schematic representation of the decay of charge during the initial
period is given in Figure 8. The first particles adhering to the aluminum
foil lost most of their negative charge to the aluminum foil very quickly.
Particles arriving later and depositing on these initial particles were par-
tially insulated from the aluminum foil. Some of the negative charge was
lost to the air, but also some negative charge flowed to the aluminum foil.
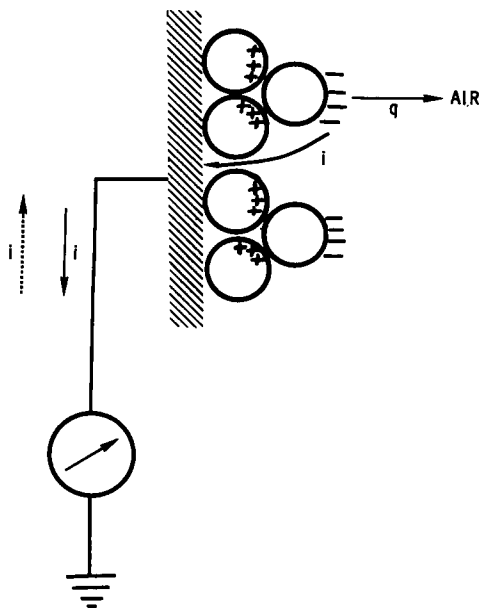
Fig. 8. Schematic representation of the decay of charge in the initial period.

This charge flowing to the aluminum foil was the charge flow measured during the first second. The high charge on the incoming particles apparently induced a positive charge on the lower particles. This was then neutralized by electrons flowing back toward the aluminum foil during the next 1 to 5 sec.

Confirmation for the loss of charge to the air can be seen in the coulombs per gram as a function of the amount of powder deposited in Figure 6. As more powder was deposited, there was less charge flowing to the aluminum foil. Then, charge flowed to air because of insulation of the aluminum foil by the initial deposited powder.

From the charge-per-gram measurements, it was possible also to calculate the average charge per particle. For the No. 2 White Thermoplastic Acrylic powder sprayed at 100 kV, 4×10^{-7} coulombs were measured and 0.233 g was deposited. This gives 1.72×10^{-6} coulombs per gram. The aluminum foil was photographed in 12 different areas at 100X, and the number of particles on the sheet was estimated at 5.7×10^{6} particles. This gives an average of 7×10^{-14} coulombs per particle, or the order of 10^{-13} coulombs per particle initially. Zabel and Estcourt[4] report the initial charge per powder coating particle to be of the order of 10^{-12} coulombs per particle. There are two experimental differences from this work[4] and the present work which account for our results being an order of magnitude lower. First, a sharp point was used for the voltage generation which would create higher electric fields than that generated in the laboratory electrostatic spray gun. Second, only a few particles were in the electric

field, while in these present measurements many particles are in the field which shield one another and give a lower charge on each particle.

Long-Term Decay

A schematic representation of the Keithley static detection system with a Model 2501 static detection head is given in Figure 9.[10,11] When the Keithley 2501 static head is used with the painted surface grounded and a layer of charged insulating powder on that surface, the Keithley reading will be proportional to the charge on the paint. The proportionality factor would be difficult to estimate.

A typical log voltage decay curve is shown in Figure 10. The powder coating was the No. 1 Beige Thermoplastic Acrylic. The process known as curve peeling shows that the curve consists of two straight lines. In this technique, the straight-line portion from 350 to 700 sec is subtracted from the voltage from 10 to 300 sec, which gives another straight line for the time period of 10 to 300 sec. This effect is a function of relative humidity. Some samples give only one straight line. The extrapolation of the lines to time zero give the initial voltages V_1 and V_2. It is possible to sum the voltages to give $V_1 + V_2$, the total voltage of the sample, and the percentage V_1 of the sum. The slopes of the lines give the product of the resistance and capacitance R_1 and C_1, R_2 and C_2 of the coating. These products are the time constants τ_1 and τ_2. The time constant gives the amount of time required to remove 63.2% of the initial charge. The larger the time constant, the more tightly the charge is being held. The smaller the
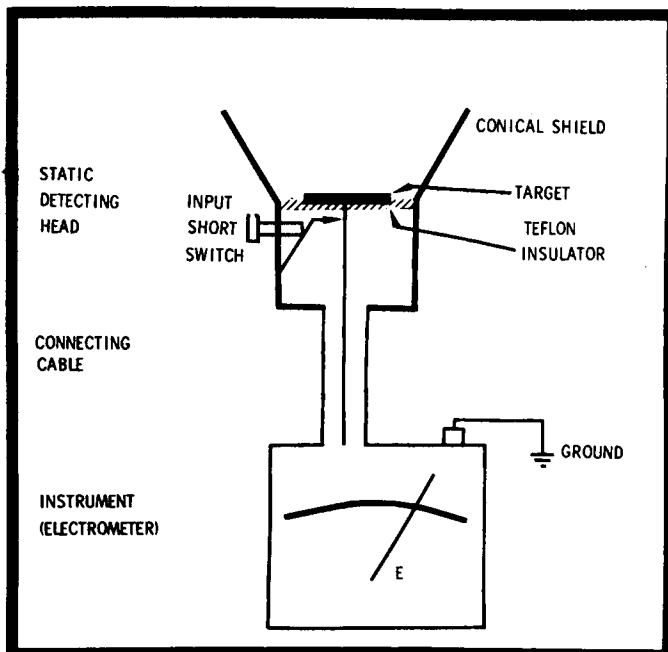

Fig. 9. Schematic representation of a Model 2501 static detection head.

TABLE II
Reproducibility of Voltage Results at 55% Relative Humidity and 75°F

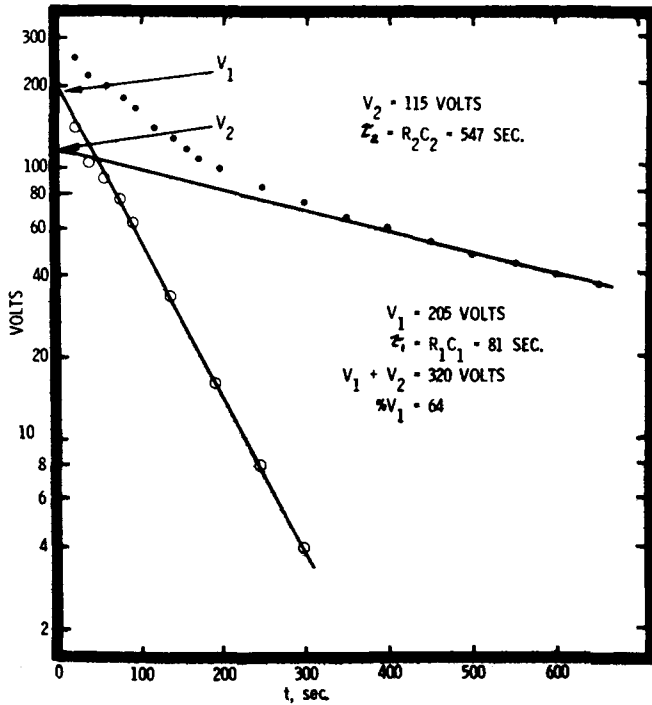| Number of times charged	V_1, volts	τ_1, sec	V_2, volts	τ_2, sec	$V_1 + V_2$, volts	% V_1
No. 1 Beige						
1	205	81	115	547	320	64
2	190	59	130	324	320	59
3	250	55	120	358	370	68
4	230	79	95	449	325	71
5	270	61	94	409	364	74
1	170	63	82	333	252	68
2	200	55	92	315	292	69
No. 1 Red						
(deposited, then read)						
1	64	57	480	166	544	12
(charged, then read)						
2	85	41	460	211	545	16

Fig. 10. Voltage decay of the No. 1 Beige at 59% relative humidity and 75°F.

time constant, the more quickly the charge is lost. It is seen that if the curve itself is extrapolated to zero time, the result is slightly more than 300 volts, which is the result from the sum of the peeled lines.

The reproducibility of the charging and measurement processes is given in Table II for the No. 1 Beige and the No. 1 Red Thermoplastic Acrylic

TABLE III
Effect of Relative Humidity on Voltage Decay of
Thermoplastic Acrylic Powder Coatings

Panel no.	Powder no. and color	Relative humidity, %	V_1, volts	τ_1, sec	V_2, volts	τ_2, sec	$V_1 + V_2$, volts	% V_1
P88	1 Red	25	0	—	440	1,600	440	0
		45	105	61	370	1,500	475	22
		60	220	82	220	900	440	50
		80	200	43	285	600	485	41
P114	2 White	25	30	—	610	4,980	640	5
		45	110	59	505	3,000	615	18
		60	230	84	410	1,700	640	36
		80	310	36	420	1,010	730	43
P117 Sect. #1	2 White	25	20	—	390	2,670	410	5
		45	50	197	370	2,900	420	12
		60	130	116	290	1,470	420	31
		80	210	45	280	870	490	43
P143 Sect. #3	4 White	25	0	—	572	16,400	572	0
		45	0	—	540	9,100	540	0
		60	80	48	430	3,940	510	16
		80	56	48	430	2,140	486	12
P92	5 White	25	0	—	558	4,890	558	0
		45	0	—	560	2,900	560	0
		60	70	51	470	2,160	540	13
		80	200	26	490	1,530	690	29
P147 Sect. #1	3 Blue	25	0	—	762	23,700	762	0
		45	0	—	760	6,290	760	0
		60	75	50	700	6,640	775	10
		80	60	43	720	2,600	780	8
P150 Sect. #1	6 Blue Metallic	25	10	—	560	3,990	570	2
		45	10	—	520	2,670	530	2
		60	47	65	470	1,260	517	9
		80	105	31	460	890	565	19

powder coatings.   With the No. 1 Red, the powder was deposited and the panel voltage was measured.   Then, the panel was recharged by charging with the gun and the voltage read.   Both processes gave similar voltage readings and voltage decays.

Table III gives the effect of relative humidity on the voltage decay of thermoplastic acrylic powder coatings.   The colors studied were red, white, blue, and blue metallic.   Table III shows that the charge decay is greater at higher relative humidities and that the percentage of V_1 essentially increases as the relative humidity increases.   For five of the seven coatings, the total voltage increased as the relative humidity increased.   We can see the effect of powder coating pigmentation on charge decay in Table III. The powders No. 1 Red, No. 2 White, and No. 3 Blue had essentially the same organic composition but varied in pigmentation.   The red pigment lost the charge the most rapidly, the white pigment next, and the blue pigment held the charge the longest.
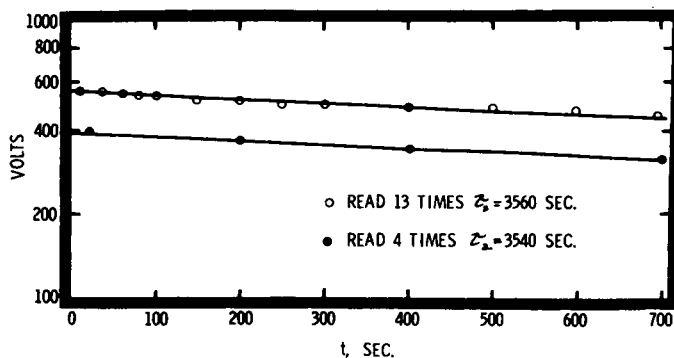
Fig. 11. Effect of number of voltage readings on voltage decay of No. 2
White Thermoplastic Acrylic powder coating.

Table IV gives the voltage decay constants for several classes of powder coatings. From Tables II–IV, there were essentially three classes of powders with regard to the percentage V_1 of the total voltage $V_1 + V_2$: those that were 10% to 20%, those that were 30% to 40%, and those that were greater than 50%.

It is seen from Tables II–IV that the composition, i.e., pigmentation and resin type, markedly affected discharge characteristics. Using these charge measurement techniques, it is possible to determine the effect of powder coating composition on both charge decay and deposition characteristics. Also, it is noted that the values of τ_1 are not that different from each other, varying only from 20 to 200 sec, while τ_2 varied from 200 to 17,000 sec. This is a factor of 10 compared to a factor of almost 100. Finally, from Tables III and IV it is seen that V_1 and τ_1 are primarily determined by the interaction of the powder with water; V_2 and τ_2 are both affected to a smaller degree by water and are primarily determined by the powder coating resin and pigment type.

Figure 11 gives the effect of the number of times the voltage measurement was taken on the voltage decay of separate panels of the No. 2 White Thermoplastic Acrylic powder coating. It is seen that, whether four readings or 13 readings were taken, the voltage decay was constant. This is experimental confirmation that the static probe did not influence the decay.

Figure 12 gives the effect of having separate panels either on the grounded aluminum plate or insulated on a rubber pad during voltage decay. The panel on the rubber pad was moved with a wooden stick. It is seen that the decay was the same whether the panels were grounded or ungrounded. To obtain constant decay mechanisms, i.e., charge decay to ground and/or air, the panels were all grounded during the long-term decay measurements. These data suggest that long-term charge decay is primarily to the air.

It was noted earlier that zinc phosphated steel panels were used as substrates for the charged panels. Bare zinc phosphated panels were sprayed

TABLE IV

Voltage Decay of Several Classes of Powder Coatings

| Panel no.	Powder no. and color	Relative humidity, %	V_1, volts	τ_1, sec	V_2, volts	τ_2, sec	$V_1 + V_2$, volts	$\% V_1$
P292	Blue Thermoplastic Metallic Acrylic No. 7	30	0	—	540	5,940	540	0
P369	Blue Thermoplastic Metallic Acrylic No. 8	46	60	62	11	690	71	85
P334	White Thermoset Acrylic No. 1	46	410	71	410	650	820	50
P393	White Thermoset Acrylic No. 2	29	0	—	850	14,600	850	0
P278	Beige Thermoset Acrylic No. 3	38	20	—	580	9,800	600	3
P273	Dark Green Thermoset Acrylic No. 4	38	0	—	170	9,600	170	0
P373	Blue Thermoset Metallic Acrylic No. 5	45	68	89	24	1,010	92	74
P321	Red CAB No. 1	32	0	—	380	4,070	380	0
P316	White CAB No. 2	32	0	—	540	2,540	540	0
P288	Blue Epoxy No. 1	30	10	—	225	10,100	235	1
P361	White Epoxy No. 2	47	620	61	460	430	1,080	58
P304	Gray Epoxy No. 3	42	0	—	490	11,100	490	0
P395	White Epoxy No. 4	29	0	—	600	13,700	600	0
P399	White Epoxy No. 5	29	0	—	1,280	10,900	1,280	0
P380	Unpigmented Polyethylene No. 1	25	0	—	890	4,400	890	0
P384	Yellow Polyethylene No. 2	25	0	—	940	3,300	940	0
P330	Orange Polyterphthalate No. 1	35	0	—	490	16,000	490	0
P325	White Polyterphthalate No. 2	35	0	—	500	11,300	500	0
P268	Unpigmented Polypropylene No. 1	25	0	—	860	14,600	860	0
P269	Unpigmented Nylon 11 No. 1	21	180	28	480	800	660	27
P355	Red Polyester No. 1	48	98	44	390	6,500	488	20
P365	Black Polyester No. 2	47	50	—	450	4,100	500	10
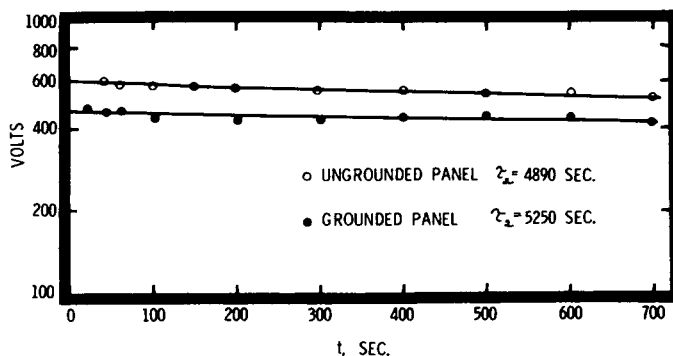
Fig. 12. Effect of ground on voltage decay of No. 2 White Thermoplastic Acrylic powder coating.
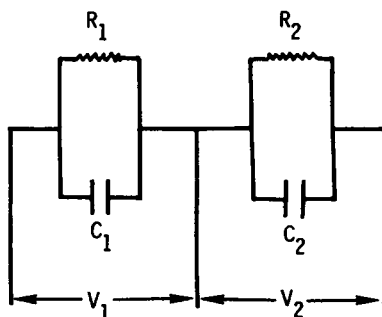

Fig. 13. Model for long-term electrostatic charge decay of powder coatings.

with charged air only. When the voltage measurement was made, no charge was detected; therefore, the zinc phosphate coating is not retaining a charge and interfering with the measurements.

It is possible to construct a model which is consistent with the observed charge decay data. This model is given in Figure 13. The model consists of two resistor-capacitors in series. The powder coating is described by the two capacitors in series. In those samples where one time constant, τ_2, is measured, τ_1 is too small to be measured. From Figure 13, the total voltage $V(t)$ as a function of time is

$$V(t) = V_1 e^{-t/\tau_1} + V_2 e^{-t/\tau_2} \tag{2}$$

where τ is the time constant $= R_1 C_1$ and $R_2 C_2$; and V_1 and V_2 are the initial voltages. This model describes quantitatively (1) the charge retention and decay of powder coatings during the long-term decay and (2) the effect on decay of coating composition and relative humidity.

To summarize the charge retention and decay for both the initial and long-term phases, loss of charge occurs over four time scales through five processes. First and second, charge flows to the air and to the panel, which occurs during the first second. Third, the flow of charge was back

TABLE V
Summary of Decay of Electrostatic Charge on Powder Coating Particles

Time scale, sec	Processes
0–1	Electron loss to air and flow to the panel
1–5	Electron flow back toward the panel to neutralize positive charge
5–100	Rapid decay period from powder
1,000–10,000	Long-term decay period from powder

to neutralize the induced positive charge for about 5 sec. Fourth, the loss of charge occurs for the next 100 sec. Finally, the loss of charge occurs for the next 1,000 to 10,000 sec. These time scales and processes are summarized in Table V. The charge retained on the particles can be for a very long time at low relative humidities because retained charge has been measured after several months.

In this study it was observed that there are a number of heterogeneous regions on the surface and/or inside powder coating particles. These regions retain charge in varying amounts. These regions also interact with water to different degrees. Using these measurement techniques, it is possible to obtain information about the electrostatic nature of polymer compositions.

CONCLUSIONS

The measurement of initial charge depends on the amount of powder deposited; the more powder deposited, the lower the measured initial charge. This was caused by the insulating effect of already deposited powder and loss of charge to the air.

The decay of charge for the first 10 sec proceeded by flow of charge to the air, to the panel, and to neutralize positive charge. Beyond 10 sec, the charge was held quite tightly for up to the order of 10,000 sec. Small residual charge in some cases was retained for months.

Water vapor increased the rate at which charge was lost. The charge decay at time constants of 20 to 200 sec was markedly affected by water, and voltage was developed by the interaction with water. The charge decay at 1,000 to 10,000 sec was affected to a smaller degree of water and was primarily a function of composition.

There was evidence of considerable heterogeneity with regard to the acceptance and decay of charge within the powder coatings. This area deserves further study.

The mathematical model constructed permitted the quantitative description of charge retention and decay in the time period of 100 to 10,000 sec and longer. The techniques described in this paper permit the evaluation of electrostatic charge effects on particle transport, adhesion, and polymer electrostatic properties. This information enables the formulator to

determine the effect of powder coating composition on electrostatic behavior and ultimately on these important process properties.

The charging and discharging characteristics of the powder greatly influences the quality of the powder coating process. First, powders which lose their charge too quickly may not be transported to the target or may fall off the target before baking. Second, if the powder loses its charge in bursts rather than continuously, an uneven and pitted coating may result. Third, the higher the charge on the particles, the higher is the efficiency of collection of the powder on the part.

References

1. A. H. Joyce, *New Automotive Paint Materials and Processes and Their Effect on the Environment—Powder Painting Equipment for Automobiles,* SAE International Automotive Engineering Congress, Detroit, Michigan, January 10, 1973.

2. S. B. Levinson, *J. Paint Technol.,* **44** (570), 37 (1972).

3. L. L. Spiller, *J. Paint Technol.,* **44**(573), 98 (1972).

4. L. W. Zabel and A. R. Estcourt, *J. Appl. Polym. Sci.,* **13,** 1909 (1969).

5. K. M. Oesterle and I. Szasz, *J. Oil Colour Chem. Assoc.,* **48,** 956 (1965).

6. J. Szasz, *Ind. Fin. Surface Coatings,* **22**(270), 4 (1970).

7. H. J. White, *AIEE Trans.,* **70,** 1186 (1951).

8. J. Pomeraniec, U. G. Shapiro, and H. Mark, *Mod. Plast.,* **41,** Pt. 1, 133 (1963).

9. Keithley Instruments *Instruction Manual Models 610C, 610CR, Solid State Electrometers,* October, 1971, Cleveland, Ohio.

10. Keithley Instruments Product Notes, *Static Charge Measurements Using Keithley Equipment,* September, 1972, Cleveland, Ohio.

11. C. L. Garfinkel, personal communication.