be included in a specification for application of thermoplastic materials.

When conducted on a bituminous surface after five freeze-thaw cycles (the critical situation that is succeeding in the field), the basic bond-strength test resulted in a substrate strength of 834 kPa. From this, a value of 862 kPa was determined as the minimum bond strength that will ensure an effective life.

Secondly, a thermoplastic application temperature range was deemed important and it was determined that the range should be small. For the test material and primer, the minimum temperature was determined to be 189°C and the desirable range for maximum adhesion to be 216°C to 232°C. It is recommended that a range be included in a specification and that the range should be determined by the test method described above for the material being used. The test is simple and requires very little time. As the curves show, if the material is applied at too low a temperature, the adhesion is very poor. Therefore, a range should be set and complied with in the field.

The air temperature was determined to be irrelevant to adhesion of the thermoplastic to the pavement. For this reason, a specification should not include an air-temperature criterion but should substitute a pavement-temperature criterion.

The pavement temperature was probably the most important aspect studied. It was found that pavement temperatures are quite critical to good adhesion. At the minimum bond strength, a pavement temperature of 12.8°C was reported. This value is recommended as a minimum pavement-temperature specification. When possible, thermoplastic material should be applied to warmer pavements because this enhances the adhesion.

Finally, it was found that only under wet conditions does pavement moisture affect the adhesion. Only at 98 percent RH does the bond strength drop below the minimum acceptable value. Therefore, it is suggested that a specification should state that the pavement should be dry to the satisfaction of the inspecting engineer.

The use of thermoplastic striping "has practically doubled since 1965" (3). The system has many advantages relating to the safety of the driver and, if the early failures can be avoided, it will become a more important tool for the transportation engineer. It is believed that these specification recommendations are a step forward in reducing the losses of thermoplastic striping systems on concrete pavements. The curves presented here are a basis for determining the adhesion that can be expected under various conditions, and the test procedures provide an excellent means of obtaining quantitative data.

ACKNOWLEDGMENT

This paper was prepared as a result of a Federal Highway Administration research project. The opinions, findings, and conclusions are mine and not necessarily those of the Federal Highway Administration.

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Publication of this paper sponsored by Committee on Coatings, Signing, and Marking Materials.

Acceptance Sampling of Structural Paints

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An investigation of acceptance sampling procedures for structural paints is described. The general paint manufacturing process was briefly reviewed, and historical data on frequency of rejections under specifications formerly in use in New York State were analyzed, resulting in some

changes in those for viscosity. New York State Materials Method 6 and Federal Test Method Standard 141a (Method 1021), which cover paint acceptance testing, are compared. Current sampling plans are discussed and analyzed, and a suggested revision to the container sampling scheme is presented.

Some results are described of a project that was established to analyze various materials and develop statistically sound acceptance criteria for them. Structural paint, the subject of this paper, was the second product to be analyzed.

PAINT MANUFACTURING PROCESS

Figure 1 schematically shows a general production process for manufacturing paints. This process can be modified in several ways, such as by combining the paste and grinding tanks, by using more than one blending tank, or by combining the blending and pouring tanks. For the purposes of this study, however, we will refer to the general production process, rather than a modified one, because the portion of greatest interest to us is the pouring tank.

The general production process begins at the paste tank, where the pigment and vehicle are mixed to the proper consistency for grinding. After the paste is formed, it is placed in the grinding tank, where it is ground in a mill until it reaches the proper fineness. This is determined by running a fineness-of-grind test. From the grinding tank, the paste is transferred to a blending tank, where the remainder of the ingredients are mixed into the paint. Finally, the paint is transferred to the pouring tank, where it is pumped through a strainer into the final package for shipment.

SPECIFICATIONS

Specifications are limitations placed on products to make them consistent with engineering requirements. Buyers use appropriate acceptance sampling plans to ensure, with known risks, that the products they are purchasing are within specification limits. It must be emphasized that acceptance sampling is used to determine a course of action (accept or reject) and not to control quality (1).

Because specification limits can affect acceptance-sampling techniques, specifications should be reviewed periodically to see that they are consistent with the engineering requirements for the product. The paint specifications used in New York State evolved over the years based on performance data. Britton (2) used performance data accumulated by the state, by the National Lead Company, and in Highway Research Board publications to set specifications that would result in a 10- to 12-year life for structural paints. The rationale for specifications applicable to other field paints is not well documented, but presumably they were based on performance data. (The specifications discussed here are specifically those published by New York State on January 2, 1962, and their addenda until the completely revised edition of January 3, 1973.)

COMPLIANCE AND SPECIFICATIONS CHANGES

Data accumulated in the course of the routine acceptance testing of paints in 1970 and 1971 are summarized in Table 1, which was prepared to determine the degree of compliance with specification limits. It can be seen that, of 394 paint lots tested during the 2-year period, 207 (52.5 percent) did not meet specification requirements. However, only 30 lots were actually rejected; the other 177 were accepted for use on the basis of "substantial compliance."

The high percentage of "substantial compliance" decisions prompted a reevaluation of the specification limits. The specification limits, degree of compliance, and breakdown of failures were reviewed. It was decided that the specification limits should be kept the same, despite the large percentage of lots that were outside these limits. The only exception was that viscosity limits could be broadened without detrimental effects on paint performance. The data indicated that the viscosity limits presented problems for most paints. It was also decided that, after a revised viscosity specification became effective, acceptance by "substantial compliance" would be discontinued.

After it was decided that the specification limits for viscosity could be broadened, data on this property were statistically summarized (see Table 2). This table shows that, for structural paints, the standard deviations for viscosity obtained by combining data from all producers ranged from 3.4 to 4.3 Stormer-Krebs units. [The Stormer-Krebs unit is an index of paint viscosity derived from a chart for classifying consistency. It is a tabulation by the drive weight (in grams) against the time (in seconds) for 100 revolutions of a paddle; thus, if 500 g caused the paddle to make 100 revolutions in 30 s, the material being tested would have a consistency of 112

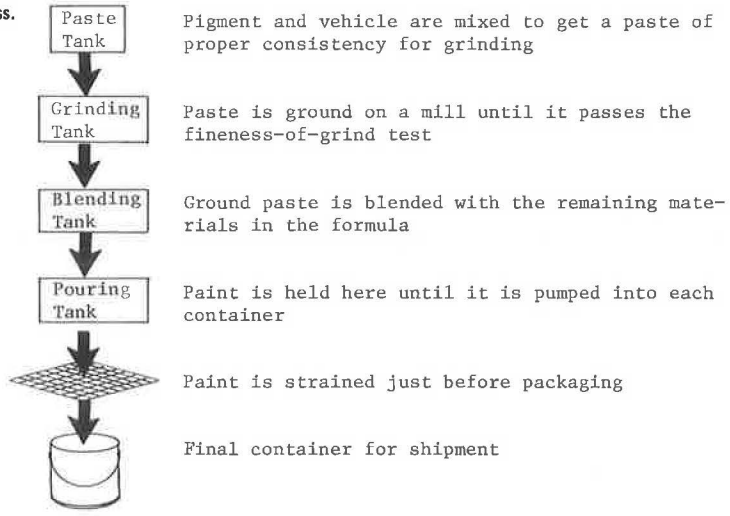


Figure 1. General paint production process.

Stormer-Krebs units.] From these standard deviations—understanding that the standard deviation for any individual producer should be smaller—the specifications for structural-paint viscosity were revised to allow a range of 20 Stormer-Krebs units. Similarly, the viscosity limits for textured concrete paint were changed to allow a range of 40 Stormer-Krebs units, as indicated in Table 3. The viscosity limits for white curb paint were changed to allow a range of 20 Stormer-Krebs units. Some changes were also made in color specifications, but these were rather arbitrary, subject to change from time to time, and will not be addressed further here because they are not directly related to performance and durability.

As mentioned above, after the specifications were changed as shown in Table 3, acceptance by "substantial

Table 1. Rates of rejection and noncompliance with specifications: 1970-1971.

Specification Item No.	Paint	Total No. of Lots	Lots Rejected		Lots Accepted Under "Substantial Compliance"		Lots Not Complying To Specifications	
			N	Percentage of Total	N	Percentage of Total	N	Percentage of Total
M18B	Maroon primer	3	1	33.3	0	0.0	1	33.3
M18CA	Dull orange primer	131	3	2.3	46	35.1	49	37.4
M18D	Black	2	0	0.0	1	50.0	1	50.0
M18E	Stain-resistant white	26	2	7.7	20	76.9	22	84.6
M18G, GA, GY	Gray	60	0	0.0	34	56.7	34	56.7
M18GR	Fast-drying white guiderail	15	1	6.7	7	46.7	8	53.3
M18GZ	Light gray	4	2	50.0	2	50.0	4	100.0
M18HA	Gray-green	2	0	0.0	0	0.0	0	0.0
M18J	Aluminum (types 1 and 2)	20	5	25.0	8	40.0	13	65.0
M18K	Zinc chromate primer	6	0	0.0	4	66.7	4	66.7
M18M	White curb	15	3	20.0	7	46.7	10	66.7
M18SH	Sage green	77	6	7.8	35	45.5	41	53.2
M18TA	Textured concrete gray finish	33	7	21.2	13	39.4	20	60.6

Table 2. Means and standard deviations for viscosity: 1970-1971.

Statistical Index	Manufacturer 1	2	3	4	5	6	7	All Manufacturers Combined
Structural paints								
Dull orange primer								
N	21		20	15	11	20	17	128
Mean	79.5		74.6	80.1	76.1	76.4	74.8	78.0
SD	3.8		2.1	2.3	1.9	3.3	4.8	4.2
Stain-resistant white								
N								26
Mean								88
SD								3.7
Gray								
N		11	15				26	60
Mean		75.7	77.4				73.3	74.7
SD		2.4	4.4				2.2	3.4
Fast-drying white guiderail								
N							15	15
Mean							77.5	77.5
SD							3.4	3.4
Sage green								
N		17	15				27	72
Mean		77.3	74.0				78.7	76.6
SD		4.8	3.8				3.2	4.1
Other field paints								
White curb								
N								13
Mean								84.5
SD								6.0
Textured concrete gray finish								
N							19	33
Mean							127.0	125.0
SD							8.5	8.3

Table 3. Specification changes.

Paint	Viscosity Range (Stormer-Krebs units)		Tristimulus Values				Trilinear Coordinates					
			Old				Old			New		
	Old	New	x	y	z	New (y only)	x	y	z	x	y	Other
Dull orange primer	74-85	69-89										None
Stain-resistant white	80-90	75-95										Total carbonate = 2.04+
Gray	72-82	67-87				9.0-10.0	0.374	0.415	0.211	0.300-0.335	0.320-0.355	None
Fast-drying white guiderail	70-78	65-85										None
White curb	70-85	68-88										None
Sage green	70-80	65-85	16.17	19.64	13.69	14.4-24.8	0.327	0.397		0.278-0.376	0.334-0.460	None

compliance" was dropped in favor of strict enforcement. All producers doing business with New York State were notified of this change by letter. Since the changes went into effect in October 1972, data have been collected that show dramatic improvement in compliance (see below).

Paint	Total No. of Lots	No. of Lots Rejected	Percentage of Lots Rejected
Dull orange primer	104	12	8.6
Stain-resistant white	24	8	33.3
Gray	80	10	12.5
Fast-drying white guiderail	54	8	14.3
Sage green	87	7	12.4
All combined	349	45	12.9

To cite one example, there was 52.5 percent noncompliance before October 1972 and 12.9 percent thereafter. This improvement could not be wholly attributed to the specification change, but is more likely due to elimination of "substantial compliance." In fact, looking back, elimination of all noncompliance due to viscosity would only reduce noncompliance by 18 percent (rather than the 39.6 percent actually experienced). After elimination of "substantial compliance," manufacturers have probably watched their processes more closely because they know that no specification limits will be waived.

CURRENT ACCEPTANCE PLANS

Background

In designing acceptance sampling procedures, one usually must study the production process. From such a study, information is obtained concerning sampling location and a rational lot. The latter should consist of production units that have low variability and are produced under the same conditions. The location of sampling should be where there is a common element from process to process, and the most logical one for paint as a finished product should be as it leaves the pouring tank. However, it is not always possible to sample at this location; sometimes it is physically impossible or too dangerous, and at other times inspection personnel cannot be present during the pouring operation. Thus, two different sampling procedures have been developed—one for paint sampled at the pouring tank and a second for paint sampled from containers. The procedures to be followed for both cases are specified in New York State Materials Method 6 (NYSMM 6), issued in February 1970. When sampling from pouring tanks, this method requires that the plant inspector draw two 0.95-L (1-qt) samples directly from the (pouring) tank pouring spout, one after approximately one-third and the other after approximately two-thirds of the pour is completed.

For sampling canned paints, the procedure requires that the inspector examine the labeling of each container to ensure that all paint is from the same batch and that all was mixed at the same time in the same pouring tank. Then, the inspector is required to sample a number of containers at random after the contents of each have been thoroughly mixed. The number of containers to be sampled is determined by the lot size as follows:

Lot Size (total containers from same pouring tank)	Sample Size (containers to be sampled)
1 to 15	3
16 to 25	4
26 to 90	6
91 to 150	8

Acceptance is judged on the basis of a uniformity test and a chemical analysis as follows. In the case of sampling from the pouring tank, the two 0.95-L (1-qt) samples are tested for fineness of grind, unit weight, and viscosity. The results of these measurements for each sample are compared to determine uniformity. Uniformity tests are performed first because the full chemical analysis of paint is very time-consuming and expensive. If a paint should fail the uniformity criteria, then it is rejected without performing the full chemical analysis.

The two samples are said to be uniform if they vary by no more than 1.0 unit for fineness of grind, 0.04 kg/L (0.3 lb/gal) for unit weight, and 3.0 Stormer-Krebs units for viscosity. If the paint has been judged uniform, then a complete chemical analysis is performed on one of the samples. If the properties checked in the chemical analysis are within the specified limits, the paint is accepted for use; otherwise, it is rejected.

Similarly, the paint samples recovered from containers are screened by testing each for fineness of grind, unit weight, and viscosity. If no two samples differ by more than the tolerances stated for sampling from the pouring tank, then the lot is judged uniform and one sample is used for a chemical analysis. The lot is then accepted if the results of the chemical analysis are within the specification limits. If the samples fail the uniformity test, then the lot is rejected without doing the chemical analysis.

Efficiency of the Plans

In determining the efficiency of acceptance plans, the risks desired by the consumer and the risks determined for the actual plan are compared. The consumer's risks are formulated from design and performance requirements as well as the consequences of a failure. Theoretically, risks are determined and then the sample size is computed to operate within such risks. Traditionally, sample sizes have been chosen without consideration of risks and, in most cases, without knowing the risks. Paint acceptance-sampling plans are no exception. Development of these techniques without regard to statistical theory or sampling methodology makes it very difficult to determine the risks associated with them. By using approximations of the risks based on statistical theory, the risks are shown by means of operating-characteristic (OC) curves. These curves give probabilities (Pa) of accepting lots of varying quality levels. The OC curves that we will consider are shown in Figure 2 for various sample sizes; they are based on the ratio (λ) of the standard deviation of the lot to the desired standard deviation, rather than on average quality levels [as developed by Duncan (1, p. 289)].

Sampling Plan for Pouring Tanks

As described above, two 0.95-L (1-qt) samples are taken from the pouring tank at specific times during the pour. Tolerance levels were established for unit weight, fineness of grind, and viscosity. The range of readings for each of these criteria, from the two samples, is compared with its respective specified tolerance, and it is assumed that if the range of the two samples does not exceed the specified tolerance, then the lot meets the criteria for variability. Unfortunately, there is always a risk that, even if the range from samples falls within the tolerance limit, the lot might not be uniform if a better estimate could be established. Assuming that the lot passes the initial criteria, then one sample is tested for all remaining physical and chemical properties.

The acceptance plan has been broken down into two

Figure 2. Operating-characteristic curves.

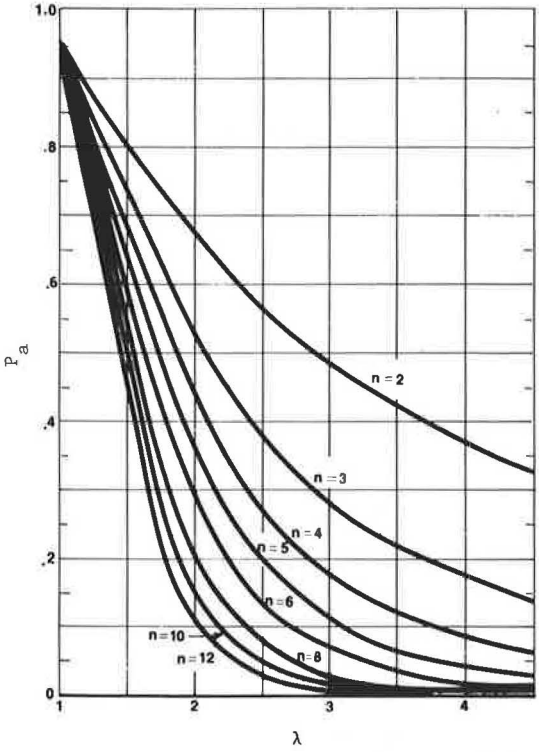
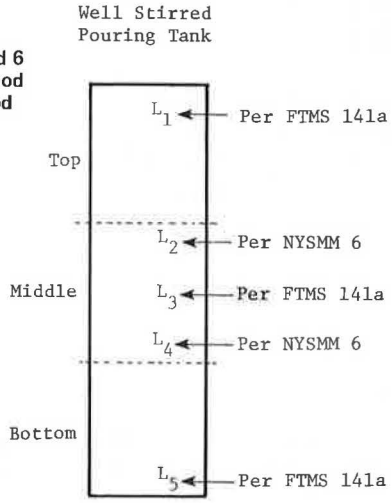


Figure 3. Sampling locations: New York State Materials Method 6 and Federal Test Method Standard 141a (Method 1012).



schemes. The first—uniformity testing—consists of the range of two measurements of each of the three properties used in determining uniformity. This is illustrated by the OC curve for n = 2 in Figure 2. This curve is somewhat weak; for example, if the lot standard deviation is three times the desired standard deviation, there is about a 48 percent chance of acceptance. The second scheme—chemical analysis—is performed on a single sample, provided the uniformity test was acceptable. This single-sample testing assumes that, if the uniformity criteria are met, then the single sample used for chemical analysis is representative of the production unit. The chemical analysis determines whether the ingredients are correctly proportioned. The analysis is performed without benefit of known testing error and assumes minimal sampling error (based on passing the uniformity test).

Sampling Plan for Containers

Similarly, the procedure for container sampling and testing consists of first, a uniformity, and second, a chemical analysis. The uniformity test consists of comparing the viscosity range, fineness of grind, and unit weight to the same tolerances used for pouring-tank sampling. Because the sample size for container sampling varies (from three to eight, depending on lot size), the risks associated with acceptance of paints based on this scheme vary also. As the OC curves shown in Figure 2 for n = 2 through n = 12 show, the smaller the sample size, the higher the risk associated with this scheme. This is true because the variance depends on sample size rather than on lot size. However, because the current acceptance tolerances remain the same as the sample size increases, this in effect assumes a smaller desirable standard deviation with increased sample size. This means that the larger the sample size, the more stringent the acceptance criterion really is. Thus, as sample size increases, the present uniformity tests are somewhat more stringent than are the curves shown in Figure 2. If the paint passes this uniformity criterion, then it is accepted or rejected based on one chemical analysis under the same assumptions and conditions as those of the pouring-tank sampling scheme.

Analysis of Sampling Procedures

The current sampling procedure for pouring tanks (Figure 3) takes two samples from the middle portion of the tank. By contrast, the Federal Test Method Standard 141a (method 1021) (FTMS 141a) suggests the following procedure (also shown in Figure 3).

> With large containers such as tanks or tank cars, three separate 1-qt [0.95-L] samples shall be taken, one from the top, one from the bottom, and one from an intermediate point, by means of a sampling tube, and shall be forwarded to the laboratory without mixing to permit a determination of uniformity of product as well as compliance with the specification requirements.

The federal standard does not provide any criterion for determining whether the range of the samples is too large. If we wish to use this standard, we need information on sampling-location bias, testing error, and sampling error. No historical data were available concerning these variations. Thus, two experiments were designed to provide the desired information at different degrees of accuracy. The first design required 300 complete paint tests and provided the best estimates of desired variances; it considered both New York State Materials Method 6 and Federal Standard 141a in its sampling design. This experiment should have provided the information needed to decide between the two methods and to design an adequate acceptance procedure around the sampling scheme. The second design required 138 samples and considered only Federal Standard 141a. Unfortunately, the sample sizes in both experiments were judged to be too large. New York State has been analyzing about 150 paint samples/year for the paint types considered here. Conducting either experiment would thus double or triple the work load of the testing laboratory. Because there was not enough time, money, or personpower available for such an effort, another alternative was carried out by the testing laboratory.

A smaller pilot experiment (see Figure 4) was developed to give an idea of the magnitudes of the sampling error and the within-tank variability. To obtain the data within the constraints of the laboratory, no replicates were taken, and testing error thus could not be sepa-

Figure 4. Pilot experiment.

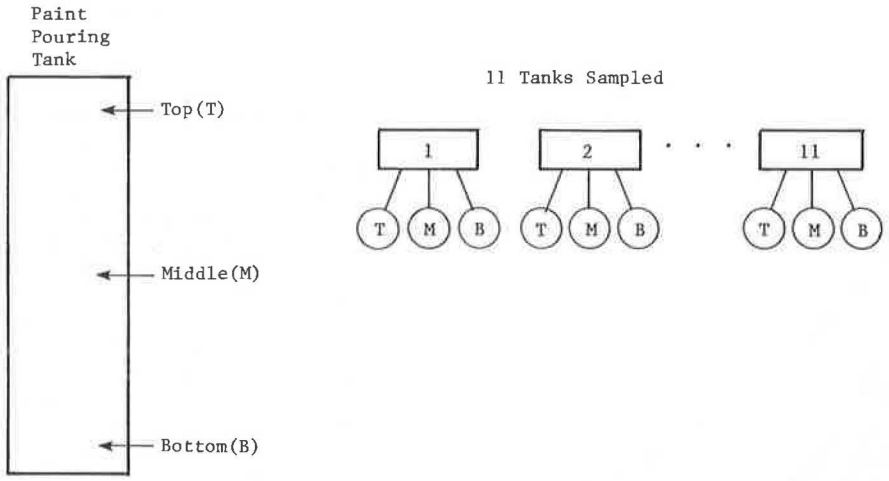


Table 4. Results of t-test to determine existence of significant differences among sampling locations.

Property	Σx^2	$\bar{x}$	$\bar{x}^2$	$(SD)^2$	SD	t
Bottom versus middle						
Pigment	0.48	0.000	0.0000	0.044	0.209	0.000
Solids	5.30	0.018	0.0003	0.481	0.694	0.082
Phthalic anhydride	0.05	-0.009	0.0001	0.004	0.067	0.426
Basic lead silico chromate	1.24	-0.091	0.0082	0.104	0.323	0.889
Viscosity	11.0	0.273	0.0744	0.926	0.960	0.898
Fineness	0.75	0.045	0.0021	0.066	0.257	0.559
Unit weight, kg/L	0.003	0.009	0.0001	0.0001	0.011	2.770
Middle versus top						
Pigment	1.18	0.054	0.0030	0.104	0.323	0.529
Solids	3.95	-0.100	0.0100	0.349	0.591	0.535
Phthalic anhydride	0.02	0.000	0.0000	0.002	0.043	0.000
Basic lead silico chromate	1.84	-0.018	0.0000	0.167	0.409	0.141
Viscosity	27.0	-0.636	0.4050	2.049	1.430	1.407
Fineness	4.00	-0.182	0.0330	0.331	0.575	1.000
Unit weight, kg/L	0.01	0.000	0.0000	0.001	0.024	0.000
Bottom versus top						
Pigment	0.56	0.054	0.0030	0.047	0.226	0.756
Solids	3.01	0.009	0.0001	0.274	0.523	0.054
Phthalic anhydride	0.02	0.018	0.0003	0.002	0.039	1.470
Basic lead silico chromate	0.66	-0.109	0.0119	0.048	0.219	1.570
Viscosity	8.00	-0.182	0.0331	0.694	0.833	0.690
Fineness	3.75	-0.045	0.0021	0.339	0.582	0.247
Unit weight, kg/L	0.003	0.008	0.0001	0.000	0.015	1.788

Note: 1 kg/L = 8.35 lb/gal.

rated from sampling error; however, if the total error were low, then both testing and sampling errors would be low. If the results of this experiment were found inconclusive or large errors and large within-tank variability were found, it would be advisable to perform the experiment outlined in Figure 3 as part of the routine testing program.

The eleven samples collected in the experiment were of three paint types, from several manufacturers. Seven properties common to most paints were selected for the actual analysis. The data were analyzed by determining differences within each sample according to the three locations tested. The differences were calculated as follows:

1. Bottom sample minus middle sample,
2. Bottom sample minus top sample, and
3. Middle sample minus top sample.

Thus, for example: 66.1 - 66.4 = -0.3.

Sample variances of the differences and the average of the differences were calculated for all seven properties at the three comparison levels. Student's t-test was used to determine whether a significant difference existed between sampling locations. The following equation was used:

$$t = [|\bar{X} - \bar{x}|\,(n-1)^{1/2}]/SD \qquad (1)$$

where

$\bar{x}$ = average of the differences for each property,
SD = standard deviation of the differences used to calculate $\bar{x}$, and
$\bar{X}$ = population mean difference to which the sample average $\bar{x}$ is compared (1).

In this experiment, $\bar{X} = 0$ because we would expect that a well-mixed paint with no significant bias due to sampling location should have a zero difference between each comparison of sampling locations.

Test results are given in Table 4. The data show no statistically significant difference at the 0.05 significance level between combinations of sampling locations, except the unit weights for the bottom versus the middle sample. Examination of the means for all properties shows that all of them approach zero, implying again that no significant bias exists due to sampling locations. These data agree with the historical data used to set the uniformity limits discussed above. Both sets of data indicate no significant bias due to sampling location, and the majority of the variations among samples can be attributed to sampling and testing errors. From these

results, it does not appear to be advantageous to change from the state to the federal test method.

SUGGESTED REVISION TO SAMPLING PLAN

When designing an acceptance sampling plan, we try to achieve the following objectives:

1. To accept products that meet the desired specifications,
2. To set the risks involved in sampling and accepting to the requirements of the consumer and still be fair to the producer, and
3. To keep the number of samples taken and the costs involved to a minimum.

Designing a plan that meets all three objectives is often impossible. Usually one or more objectives must be modified to produce a workable plan. All of these factors are considered in developing an acceptance plan for paints (1, 3, 4, 5). Paint can be considered a bulk material and could be tested as such. Bulk sampling can be broken into two major categories—segmented material and material moving in a stream. Each can be further broken down into isolated lots moving in a series. Segmented material is subjected to stratification, and stream material to segregation (4).

Data from the uniformity testing showed no significant variation in the tanks, and thus stratification in containers filled from properly mixed tanks seems unlikely. Tank sampling can be modeled as one of a series moving in a stream, and container sampling can be modeled as distinctly segmented lots in a series. Unfortunately, most of the work done on bulk sampling to date has been in prediction of the mean quality of the lot. Determination of the mean quality of the lot and its confidence limits is based on knowledge of (a) the variabilities associated with the particular material, (b) the variance between segments in a lot, (c) the variance within segments, (d) the reduction variance (reducing the total sample to a usable size for the actual testing), (e) the sampling variance, (f) the analytical variance, and (g) the segregation variance if it exists (4). The tables given above in this paper present several of these variables but not all. Additional experiments would be necessary to determine the remaining variables. The problem, however, is that this analysis should be run for each producer, each type of paint, and all properties and occasionally all analyses should be rerun to ensure that none of the variances has changed significantly. Each analysis would require a large number of calculations. This indicates that such a variables plan for acceptance, based on the mean quality of the lot, would be very time-consuming and expensive and probably not justified based on the criticality of a failure. The risks taken in accepting paints can far exceed those for the strength of steel, reinforcing bars, or concrete used in the structure to be painted. If a variables sampling plan were constructed and used, the result would be that a separate plan would be needed for each property of each type of paint. In the case of tank sampling, had either of the two designed experiments been carried out, it would have been possible to assess sampling and testing variations and to develop a sampling plan that had fewer assumptions. Because the experiment actually performed did not lend itself to such detail, the following was deduced. As discussed above, from the experiment comparing the FTMS 141a and NYSMM6, no reason was found to change to the federal test method. If we assume that the two samples required for tank sampling adequately determine whether the material is uniform—i.e., thoroughly mixed—then it would seem reasonable to assume that a single chemical analysis such as is now performed would be adequate to characterize whether the paint meets the desired specifications. This is based on the assumptions that the bulk sample, in the form of a tank or vat of paint, can be considered a production unit and that the consequences of accepting paint that might fail are not critical enough to outweigh the increased costs of performing more than one chemical analysis. These assumptions were considered reasonable because an inspector is present at the plant to make certain that the paint is thoroughly mixed and properly prepared in the process from which he or she is about to sample. An approximate OC curve for the two-sample uniformity test from tank sampling is the n = 2 curve shown in Figure 2.

In the case of container sampling, the assumptions were somewhat different. It was assumed that an inspector was not present when the containers were filled from the pouring tank and that it was important to determine that the paint in the lot of containers was from the same production unit, as required by the specifications. As noted above, sample sizes from containers vary according to the number of containers in the lot, and the uniformity test ranges (viscosity, fineness of grind, and unit weight) are required to meet the same tolerance applied to the two samples taken when sampling from pouring tanks. From statistical theory and acceptance sampling methodology, it is obvious that this scheme does not apply equal risks to the various production lot sizes. This type of plan has been used historically in many fields and seems rational because the sample size increases with lot size, but in fact the acceptance criteria change for each group of lot sizes. For any given lot, the larger the sample size, the larger the expected range should be. From established tables, the allowable range for two samples can be adjusted to maintain the same confidence level for increased sample sizes. The following table permits comparison of allowable ranges based on the uniformity tolerances for two samples and the assumption of an 0.05 significance level:

	Acceptance Tolerance for Sample Size				
Test	Of 2	Of 3	Of 4	Of 6	Of 8
Viscosity, Stormer-Krebs units	3.0	3.58	3.93	4.36	4.65
Unit weight, kg/L	0.4	0.04	0.05	0.05	0.05
Fineness of grind, units	1.0	1.19	1.31	1.45	1.55

These values were found by using the equation $\sigma = R/W$, where σ is known and W is determined by using the sample size and special tables and solving for the new allowable range (1). From this comparison, it can be seen that, by applying the same tolerances used for two samples, the larger the sample size, the tighter the standards of acceptance become.

If we were to apply the appropriate tolerances to each sample size, then the OC curves for such sampling plans would approach those shown in Figure 2. It can be seen that the probability of acceptance of a material that has a standard deviation three times as large as that desired does not fall below 10 percent until a sample size of eight is reached. Because this ought to be only a minimum criterion for a noncritical material such as paint, it was decided that a new sampling scheme for containers was in order. A suggested scheme would be to sample all containers if the lot consists of eight or fewer and eight if the lot consists of more than eight. This sample would undergo the uniformity testing and be judged against the appropriate tolerances for the sample size. If the paint from the containers passes the uniformity

criteria, then it should be assumed that all were containers filled from the same well-mixed vat of paint and, for the reasons discussed above in pouring-tank sampling, one chemical analysis on one sample should suffice. Also, it is worthwhile to note that, for sample sizes of 10 and 12 in Figure 2, the greater protection afforded by these sample sizes over that chosen (eight) does not justify the increased testing efforts that would be involved. Furthermore, because of methods of determining probabilities (which we will not discuss here) for small lot sizes, the OC curves shown in Figure 2 would be somewhat conservative and probably represent the worst case.

CONCLUSIONS

1. It was determined from historical data that the limits for viscosity of paint could be broadened.
2. The practice of accepting paints on the basis of "substantial compliance" with the specifications was eliminated, and this was believed to aid in improving the overall quality of paints accepted by causing producers to pay closer attention to their manufacturing processes.
3. No advantage was found for replacing NYSMM6 by FTMS 141a (method 1021).
4. It was determined that, if the uniformity criteria are met, then it is practical to assume that a paint lot can be considered as one bulk unit for further chemical analysis.
5. A new sampling scheme is suggested for container sampling.

ACKNOWLEDGMENTS

This paper was prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

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Publication of this paper sponsored by Committee on Coatings, Signing, and Marking Materials.

Accelerated Performance Testing of Bridge Paints for Seacoast Environments

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The design and operation are described of an accelerated-corrosion-environment chamber for evaluation of metal protective paints. The findings are discussed of experiments designed to test the reproducibility of the results obtained in the chamber and are correlated with the limited available data from an exterior weathering test fence at a tidal estuary in Brunswick, Georgia. The fundamental premise underlying the design of the chamber is that the primary stresses that account for paint-system failures on structural steel in seacoast environments are caused by continuing cycles of wetting and drying and heating and cooling in the presence of the corrosion-stimulating chloride ion. The major conclusions are that the chamber exhibits high precision of test results within runs and an exceptionally close similarity in a greatly accelerated test to the modes of panel failure observed in the field. The prospects for close laboratory-field correlation appear very good but, for general use, this correlation will require control system techniques that have been proposed but not yet validated by comprehensive experimental studies.

Research on accelerated-weathering devices spans a period of one-half century. During the 1920s, Nelson and co-workers (1, 2, 3, 4) developed artificial weathering machines and investigated various exposure cycles. An interesting illustrated review of much of this early work has been given by Gardner (5). Standard methods for operating weathering equipment (6) and preparing and evaluating test panels (7) were developed and published by the American Society for Testing and Materials (ASTM) during the 1930s.

Notwithstanding the intensive research over an extended period of time, difficulties in obtaining similar results from different machines and in correlating these results with field experience have continued to create problems (8). The multiplicity of factors involved in accelerated weathering and corrosion tests was discussed at length in 1963 by Valentine (9) and by Talen (10) (particularly, the aging process). Clearly, the problem of defining and measuring some important fundamental properties and variables had not been specifically addressed, and no evidence was seen of any effort to formulate a comprehensive physical theory of the performance of anticorrosive paints. Thus, in 1967, Burns and Bradley (11) referred to laboratory-field correlation research as follows: "This correlation has never been achieved despite the efforts of many laboratories over a period of many years." Later, however, in referring to the work of Gay (12), they observe that "The significant