NATIONAL BUREAU OF STANDARDS REPORT

2560

A TESTING PLAN FOR CEMENT

By

W. H. Clatworthy, W. S. Connor, and D. N. Evans

U. S. DEPARTMENT OF COMMERCE
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FOREWORD

This report illustrates a statistical approach of wide applicability, and was prepared in the Statistical Engineering Laboratory of the National Bureau of Standards, for the information and use of the Bureau's Mineral Products Division.

Churchill Eisenhart
Chief, Statistical
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A TESTING PLAN FOR CEMENT

By

W. H. Clatworthy, W. S. Connor, and D. N. Evans

1. Introduction. This report studies the amount of testing which is being done by the National Bureau of Standards of cement produced by the Hermitage plant at Nashville, Tennessee. The object of the report is to determine whether the present testing program provides enough testing or too much testing of Hermitage production, and if too much, to suggest an alternative program. Such an alternative testing program should be simple to apply and applicable to the production of any plant.

The data studied were taken from the files of the Concreting Materials section of the Mineral Products division (9.6) of the National Bureau of Standards. The data are the results of tests made on grab samples taken from Hermitage production of Type II cement during the period January, 1952 through May, 1953. The properties studied are sulphur trioxide (SO_3), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), magnesium oxide (MgO), autoclave expansion, 7-day strength, and air permeability fineness (A.P.F.).

Most bins sampled contained 4500 barrels, from which 9 samples were taken. Except for fineness, composite samples were formed from the first and second sets of four samples each, leaving a single sample to be tested as an individual. Fineness determinations were made of each of the 9 individual samples. From these we have chosen the first and fifth. For the purposes of this study the data have been split into test results for composite samples, which are given in Table 1, and those for individual samples, which are given in Table 5.

A proposed testing plan is described in section 3, applied to tests of composite samples in section 4, and applied to tests of individual samples in section 6. The reasoning underlying the plan is developed in section 5. The conclusions are presented in the following section.

2. Conclusions. The testing plan which is described in section 3 is simple to apply, and can be used either for composite samples or for individual samples. If it had been applied to the Hermitage plant from the middle of October, 1952 to the middle of May, 1953, then for SO_3, SiO_2, Al_2O_3, MgO, autoclave expansion, and 7-day strength it would have reduced the number of tests from 762 to 333. For SO_3 the proposed testing plan would not have materially reduced the number of tests. However, for the other properties considered the number of tests would have been reduced to approximately one-third as many tests as were actually made. This reduction would have been achieved at no appreciable increase in the risk of failing to detect violations of the specifications.

The plan is general. Barring some factors or conditions not found in the cement studied, it can be applied to grab samples from any plant and to properties other than those studied. It also can be modified to apply to shipping and other samples.

3. <u>The testing plan</u>. We can best describe the testing plan by applying it to a particular property. So let us trace the application to SO_3 composites. For the sake of realism we shall suppose that it was decided to put the plan into effect in October, 1952, when results for bins 1 through 32 were available, but before bin 33 had been tested.

The steps in the application of the plan are as follows:

(1) From the files take the first test result for each of the last 32 bins, dividing them into groups of 8 each. These results (from Table 1) are as follows:

Group 1	Group 2	Group 3	Group 4
1.4	1.5	1.4	1.8
1.6	1.7	1.6	1.7
1.7	1.4	2.1	2.0
1.1	1.6	1.6	1.8
1.6	1.5	1.7	2.0
1.6	1.6	1.8	2.0
1.4	1.5	1.6	1.9
1.2	1.5	1.6	2.0

We emphasize that only the first result from each bin is used.

(2) Determine the range, r, of each group. The range is the difference between the largest and the smallest number in the group, so that the ranges are as follows:

	Group 1	Group 2	Group 3	Group 4
Largest	1.7	1.7	2.1	2.0
Smallest	1.1	1.4	1.4	1.7
Range (r_i)	0.6	0.3	0.7	0.3

(3) Compute the average range, $\bar{r}_1$, thus:

$$\bar{r}_1 = (r_1 + r_2 + r_3 + r_4)/4$$
$$= (.6 + .3 + .7 + .3)/4 = 0.475 \; .$$

(4) Subtract 0.7025 $\bar{r}_1$ from 2.0. (If the property has a minimum specification, add 0.7025 $\bar{r}_1$ to the specification instead of subtracting.) Round off to the same number of decimal places as are recorded for the test results. Obtain

$$2.000 - (0.7025)(0.475) = 1.666$$

and round off to 1.7. We shall call this value F(Frequent) to denote the limit for frequent testing.

(5) Subtract 0.7025 $\bar{r}_1$ from 1.666. (If the property has a minimum specification, add.) Obtain 1.334 and round to 1.3. We shall call this value I (Infrequent) to denote the limit for infrequent testing.

$$.7025 = \frac{u(28\,d.f.)}{d_8} = \frac{2.0}{2.847}$$

Table on p. 54 of reference [3]

Note: [illegible] since original table gives only 2 digits

(6) (Optional but recommended.) Make up a chart, such as Figure 1, showing the specification, the 32 test results, and the numbers F and I. The specification line should start with bin 1 and extend as far into the future as is feasible. The F and I lines should extend from bin 33 through 64.

The preliminary calculations are complete, so the plan may now be put into operation. The first new test result, which in our case occurs for bin 33 will determine the testing rate. If it is greater than or equal to F, we shall test frequently (two tests per bin) but if it is less than F we shall test infrequently (one test per bin). As it turns out (see Table 1 or Figure 1), the first new test result is 2.1 which exceeds F = 1.7, so that we start out testing frequently. Frequent tests continue until a test result is less than I, which is the signal for infrequent testing. The first such result occurs for bin 38, when the test result drops to 1.1, less than I = 1.3, so that we switch to infrequent testing. This continues until test result 1.7 is reached for bin 40, which again orders frequent testing. Since no further test result is as small as I, frequent tests are run for the remaining bins. Although for SO_3 F and I are unchanged throughout our illustration, we shall see below that there is, in general, the possibility that they will change after each 32 additional bins.

(7) This step is designed to keep a check on the stability of the range. When the test results for bins 33 through 64 become available, divide the first test results of the bins into 4 groups of 8 each, and compute the range of each group, and the average range, $\bar{r}_2$. Then form the ratio of the larger of $\bar{r}_1$ and $\bar{r}_2$ to the smaller. If the ratio is less than 1.5, continue to use F and I as previously computed through bin 96. If step (6) is in use, we now extend our original F and I lines through bin 96. If the ratio is as great as 1.5, use $\bar{r}_2$ to recompute F and I according to steps (1) through (5), and draw new F and I lines. After each additional 32 bins, we compare the new $\bar{r}$ with the $\bar{r}$ in use to decide whether we need to recalculate F and I.

For SO_3 the calculations are as follows:

	Group			
	1	2	3	4
	2.1	1.8	1.6	1.7
	1.9	1.7	1.7	1.7
	1.9	1.7	1.8	1.6
	2.0	1.7	1.8	1.7
	1.4	1.9	1.7	1.4
	1.1	1.6	1.8	1.7
	1.6	1.8	1.6	1.8
	1.7	2.0	1.4	2.0
Largest	2.1	2.0	1.8	2.0
Smallest	1.1	1.6	1.4	1.4
Range (r_i)	1.0	0.4	0.4	0.6

$$\bar{r}_2 = (r_5 + r_6 + r_7 + r_8)/4$$

$$= (1.0 + 0.4 + .04 + .06)/4 = 0.600$$

$$\bar{r}_2/\bar{r}_1 = .600/.475 = 1.26$$

Since 1.26 is less than 1.50, we continue to use F = 1.7 and I = 1.3. Thus, the F and I lines have been extended through bin 74 in Figures 1 and 4, and in practice would be extended through bin 96. This complete the description of the plan.

It is apparent that with rare exceptions SO_3 needs frequent testing. The testing plan would have reduced the number of tests by only four tests. We determine this by remembering that two composite samples and one individual sample actually were tested on all bins except bin 51, for which three composites and one individual were tested. Hence, if when our plan requires frequent tests we include the individual sample for each bin, we find that one composite and one individual test would have been saved for each of bins 38 and 39. This is a reduction of 4 tests out of 127 tests.

4. <u>Application of the plan to composite samples for several properties</u>. We have seen that SO_3 is running so close to the specification that frequent testing is almost always necessary. We now shall consider composite sample test results for several other properties, SiO_2, Al_2O_3, MgO, 7-day strength, and autoclave expansion. These results are given in Table 1.

We shall see that the testing plan of section 3 would have required many fewer tests than actually were made during the period considered.

Table 2 supplies the necessary calculations for determining F and I. Perhaps the most striking property for which infrequent tests would have sufficed throughout the period is autoclave expansion. Autoclave never came close to specification, nor for that matter to I. The testing plan for autoclave is vividly depicted in Figure 2. The first test result for bin 33, .15, is much smaller than I = .38, so from the beginning the plan calls for infrequent testing. Since the largest test result during the period was .33 (bin 67), much less than F = .44, the plan never requires frequent testing.

Let us count the saving in the number of tests which the testing plan would have provided. As the testing was really done, one individual and two composite tests were run on every bin but one, and that bin (bin 51) had three composites and one individual, giving a total of 127 tests. The testing plan, on the other hand, would have required only one test per bin, or 42 tests altogether. Thus, the plan would have cut the number of tests to one-third.

The same saving would have been realized for SiO_2, Al_2O_3, MgO, and 7-day strength. Using only the first sample for each bin the smallest test result for SiO_2 was 21.9 (bin 73), greater than F = 21.6; the largest for Al_2O_3 was 5.3 (bins 62 and 72), less than F = 5.6; the largest for MgO was 4.4 (bin 72), less than F = 4.5; and the smallest for 7-day strength was 1960 (bin 60) greater than F = 1,870. Hence, for each of these properties infrequent testing would have sufficed.

To summarize, the testing plan would have reduced the number of tests for each of autoclave, SiO_2, Al_2O_3, MgO, and 7-day strength from 127 tests to 42 tests, or altogether from 635 tests to 210 tests.

5. Rationale of the testing plan. We consider a testing plan to be a good one if it prescribes frequent tests when it is likely that a sample will violate the specification, but infrequent tests otherwise. The plan which we have described has these characteristics.

To judge whether or not it is likely that a current sample will violate the specification for some particular property, it is necessary to look at the history of that property. If past sample test results were close to the specification, then there is a good chance that the next sample will violate the specification, and frequent tests should be made. On the other hand, if history reveals that the test results were far from the specification, then there is little danger of a violation, and infrequent testing is sufficient.

The problem is to decide what is meant by a test result being close to or far from the specification. It is apparent that knowledge of the average value of past results, though important, is not enough by itself to decide this. To know, for example, that the last ten test results for autoclave expansion averaged 0.34 percent does not enable us to judge whether or not a new sample will exceed 0.50. Further scrutiny of the data is necessary. If we find that the largest of the ten was 0.48, it will seem quite possible for the new sample to violate the specification, but if the largest was only 0.37, we shall doubt that the new-sample will exceed 0.50. The average, then, has to be accompanied by a measure of the variation, and these two measures together form the basis for a sound sampling plan.

In the following remarks we shall assume that the test results are approximately normally distributed. Although we have not investigated their distribution, there is no reason to expect any serious departure from normality.

We chose the range as the measure of variation because (i) it is easy to calculate and (ii) there are long-run shifts in the average levels of the properties, which suggests that the data should be divided into groups of consecutive observations and the variation estimated within each group, a situation in which the range is nearly as efficient an estimator of the variation as is the theoretically preferred standard deviation [1]*.

Under certain circumstances, theoretical considerations show that the average of the ranges of groups of 8 tests each is a better estimator of the variation than the corresponding average for groups of any other size [2]. For this reason we have used groups of 8 tests each.

For each bin several samples are available for testing, whether we test them or not. The problem of how many samples to test for a bin can be answered by testing the first sample and judging how close the result is to the specification. This judgment should be made by consideration of the variation among samples from the same bin. The ranges which we use, based as they are on one sample per bin, do not measure this variation, but rather measure the variation among samples from different bins. We prefer to use them, however, because they are convenient, requiring only one test per bin, and they are conservative, since they tend to overestimate the variation within bins.

* See reference at end of text.

That the variation among samples from different bins exceeds the variation among samples from the same bin is brought out by Table 4. The numbers in the table were computed from the results for bins 49 through 74. The last column, "Estimated variance (or variation)", is of main interest because the first number there (between bins) estimates the variation among samples from different bins and the second number (within bins) estimates the variation among samples from the same bin. For every property the former exceeds the latter, and for some properties is several times larger.

The number F has been chosen such that if the true average for the property is equal to F, then the chance that a test result will violate the specification is only about 25 in 1,000 [3]. This is a conservative choice of F, as we shall see. Suppose that the history of the property is such that infrequent tests have been made in the recent past, but the current test result is equal to F or lies between F and the specification. We at once switch to frequent testing, taking the dim view that the true average for the property may be at least as close to the specification as F, even though the current result could be due only to sampling fluctuations or testing error when in reality the true average is not as close to the specification as F. Thus unless there is a marked trend in the data, the chance of the next test result violating the specification is not greater than about 25 in 1,000.

The number I has been chosen similarly. If the true average for the property is equal to F, then the probability of obtaining a test result which is as far from F as I is only .025. Thus, we do not resume infrequent sampling until it becomes virtually certain that the true average is not as close to the specification as F.

These remarks assume that the true variability does not change. If there is an increase or decrease in the true variability, then the probability, .025, will increase or decrease, respectively. Small changes in the variability will not affect this probability much, and so may be ignored. However, a sizeable change must be taken into account, and it is for this reason that step (7) of the plan (section 3) is included.

If $\bar{r}_1$ is the average of the ranges from 4 groups each of size 8 and $\bar{r}_2$ is a similar measure from 4 other groups, then there is good reason to believe that the probability that the larger of $\bar{r}_1$ and $\bar{r}_2$ will exceed the smaller by as much as 1.5 (when in reality they estimate the same variation) is small. Hence, we do not recompute F and I unless there is a good chance that the variation between bins really has changed.

$1.5 \times 2.8472 = 4.2708$

$P\{ \bar{R}_1 < 4.2708\sqrt{\ } \} \simeq .95$

[illegible]

To obtain a graphic picture of the stability of the range for SO_3, autoclave expansion, and 7-day strength, we have plotted ranges of groups of 4 test results each in Figures 4 and 6. Also given are the average range, $\bar{R}_1$, for the first 8 groups and a control limit which is determined from $\bar{R}_1$. Summary calculations for Figure 4 are given in Table 3. The control limit (L in Table 3) is determined such that the chance of an individual range exceeding it if $\bar{R}_1$ were equal to its expected value is only about 15 in 10,000. The fact that no individual ranges exceed the limit for any of the groups 1 through 18 attests to the stability of the process variation. This is further confirmed by calculation of $\bar{R}_2$ from the ranges of groups through 16. In no case is $\bar{R}_2$ very different from $\bar{R}_1$.

6. <u>Application of the testing plan to individual samples</u>. The testing plan of section 3 applies to individual samples equally as well as to composite samples. In Table 6 we have determined F and I for individuals for all of the properties already treated for composites, and in addition, A.P. fineness.

Since only one individual sample is available from each bin, it is impossible to show on a chart all of the test results which would be required by frequent sampling. However, Figure 5 gives a plot of the available test results for 7-day

L in table 3 = 2.38 $\bar{R}_1$

$E(\bar{R}_1) = 2.8472\,\sigma$

$P\{R < 6.88\sigma\} = .99985$ 15 in 10,000

$\frac{6.88}{2.8472} = 2.38$

strength, together with the minimum specification and the F and I lines. In practice, when a sample result is as small as F, several samples would be tested for each bin.

As one would expect, the variation among individuals tends to exceed that among composites. This can be seen by comparison of the ranges of Table 6 with those of Table 2. For 7-day strength the difference in ranges is reflected in an increase in F from 1,870 for composites to 2,080 for individuals, and an increase in I from 2,250 for composites to 2,650 for individuals.

In the application of the testing plan to 7-day strength, composite samples never required frequent testing, but individual samples oten did. In fact, the available test results for individuals ordered frequent tests beginning with bins 33, 50, and 61. For other properties studied, the plan when applied to individuals requires about the same number of tests as when applied to composites.

For autoclave, since $\bar{r}_1 / \bar{r}_2 = 1.5$ (see Table 6), F and I should be recomputed and the new values used for bins 65 through 96. F and I would then be .43 and .37, closer to the specification.

7. Acknowledgment. The authors wish to thank Dr. E. P. King (11.3) for advice about technical aspects of the use of the range.

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[2] F. E. Grubbs and C. L. Weaver, "The best unbiased estimate of population standard deviation based on group ranges", Journal of the American Statistical Association, Vol. 42, No. 238 (1947), pp. 224-241.

[3] E. Lord, "The use of range in place of standard deviation in the t-test," Biometrika, Vol. XXXIV, Parts I and II (1947), pp. 41-67.

Table 1

TEST RESULTS FOR COMPOSITES

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave
1	1/4-5/52	S-1-2	1.4	23.0	4.9	3.1	2000	.15
			1.4	23.0	4.8	3.2	2000	.15
2	1/21-22/52	S-4-2	1.6	22.5	4.8	3.1	1850	.12
			1.4	22.8	4.9	3.2	1680	.17
3	2/7-8/52	S-1-3	1.7	22.5	5.1	3.6	1790	.20
			1.6	22.6	5.3	3.6	1660	.22
4	1/25-26/52	S-5-7	1.1	22.9	5.3	3.4	1480	.15
			1.1	23.0	5.1	3.4	1520	.16
5	3/3-4/52	S-4-3	1.6	22.5	5.1	3.4	1910	.18
			1.4	23.0	5.2	3.4	1500	.16
6	3/12-13/52	S-5-8	1.6	22.4	4.7	3.0	2060	.11
			1.4	22.4	4.8	3.0	2220	.11
7	3/25-26/52	S-1-4	1.4	22.4	4.6	3.0	2020	.12
			1.4	22.4	4.6	2.9	2010	.13
8	4/2-3/52	S-4-4	1.2	22.4	4.9	3.5	2250	.13
			2.0	22.1	4.9	3.4	2210	.11
9	4/11-12/52	S-5-9	1.5	22.2	4.8	3.5	2260	.11
			1.2	22.4	5.1	3.7	1890	.17
10	4/28-29/52	S-1-5	1.7	22.5	4.8	3.1	2220	.11
			1.4	22.5	4.8	3.2	2210	.13
11	5/14-15/52	S-2-2	1.4	22.5	4.6	3.3	2090	.16
			1.6	22.6	4.5	3.3	2100	.17
12	5/26-28/52	0-1-3	1.6	22.7	4.5	3.1	2510	.12
			1.5	22.9	4.3	3.1	2300	.13
13	6/4-5/52	S-4-5	1.5	22.9	4.5	2.9	2480	.13
			1.4	22.9	4.4	2.9	2460	.14
14	6/9-10/52	S-1-6	1.6	22.4	4.8	2.9	2350	.13
			1.5	22.7	4.9	2.9	2050	.14
15	6/12-13/52	S-5-10	1.5	22.7	4.5	3.1	2350	.12
			1.5	22.7	4.6	3.1	2440	.13
16	6/23-25/52	S-2-3	1.5	22.9	4.4	3.2	2340	.12
			1.4	23.0	4.4	3.2	2460	.11
17	6/30/7-1/52	S-3-7	1.4	23.1	4.2	3.2	2000	.14
			1.6	23.1	4.3	3.2	2250	.13
18	7/14-15/52	S-4-6	1.6	22.4	4.6	4.1	1860	.17
			1.7	22.6	4.8	4.1	1800	.21
19	7/17-18/52	S-1-7	2.1	21.7	4.6	3.6	2040	.15
			2.1	21.9	4.6	3.3	1680	.16
20	7/30-31/52	S-5-11	1.6	22.2	4.6	3.8	2410	.18
			1.6	22.3	4.6	3.7	2550	.16

Table 1 (Continued)

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave
21	8/4-5/52	S-2-4	1.7	22.4	4.2	3.0	2250	.11
			1.5	22.3	4.3	3.1	2080	.12
22	8/6-7/52	S-3-8	1.8	22.1	4.0	3.1	1860	.11
			1.6	22.3	3.8	3.3	2010	.09
23	8/13-14/52	S-1-8	1.6	22.7	4.0	2.8	1980	.06
			1.6	22.5	4.2	2.7	2160	.06
24	8/18-19/52	S-4-7	1.6	23.0	4.2	2.8	2170	.06
			1.7	23.0	4.3	2.8	2280	.06
25	9/2-3/52	S-5-12	1.8	22.9	4.5	3.2	1980	.10
			2.0	22.4	4.5	2.6	2470	.10
26	9/4-5/52	S-2-5	1.7	22.6	4.5	3.1	2120	.10
			1.6	22.8	4.7	3.1	2160	.11
27	9/11-12/52	S-3-9	2.0	22.8	4.9	3.0	1880	.12
			1.8	22.9	4.8	3.2	2140	.12
28	9/15-16/52	S-1-9	1.8	22.7	4.9	3.0	1990	.17
			1.8	22.8	5.0	2.9	2000	.18
29	9/18-19/52	S-4-8	2.0	22.6	4.8	2.8	1980	.14
			2.0	22.5	4.8	2.7	2070	.16
30	9/29-30/52	S-5-13	2.0	22.3	4.8	2.9	2190	.18
			2.0	22.5	4.8	2.9	2210	.15
31	10/1/52	S-2-6	1.9	22.8	5.0	2.9	2100	.18
			1.8	22.5	5.0	2.9	2480	.20
32	10/3-4/52	S-3-10	2.0	22.5	4.8	3.0	2270	.11
			1.9	22.3	4.9	3.0	2330	.13
33	10/7-8/52	S-1-10	2.1	22.7	4.8	2.8	1990	.15
			1.8	22.6	4.9	2.9	2070	.18
34	10/7-8/52	S-4-9	1.9	22.5	4.8	3.1	2120	.13
			1.7	22.5	4.7	3.1	2200	.16
35	10/22-23/52	S-5-14	1.9	22.5	4.5	2.8	2310	.10
			1.8	22.7	4.7	2.9	2170	.13
36	10/23-25/52	S-2-7	2.0	22.8	4.8	2.9	2090	.14
			2.0	22.6	4.8	2.9	2120	.12
37	11/1-2/52	S-3-11	1.4	23.2	4.7	2.8	2560	.12
			1.5	23.1	4.6	2.6	2500	.11
38	11/3-4/52	S-1-11	1.1	22.7	4.6	2.9	2630	.09
			1.5	22.5	4.5	3.0	2620	.09
39	11/5-6/52	S-4-10	1.6	22.3	4.4	2.9	2260	.09
			1.4	22.4	4.3	3.0	2210	.08
40	11/11-12/52	S-5-15	1.7	22.5	4.7	3.3	2080	.11
			1.7	22.5	4.7	3.4	2090	.12
41	11/13-14/52	S-2-8	1.8	22.6	4.6	3.3	2130	.13
			1.7	22.7	4.7	3.3	2170	.11

Table 1 (Continued)

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave
42	11/25-26/52	S-3-12	1.7	22.7	4.5	3.0	2360	.10
			1.6	22.7	4.6	3.0	2370	.20
43	11/28-29/52	S-1-12	1.7	22.7	4.6	3.0	2080	.09
			1.5	22.7	4.9	3.0	2050	.10
44	12/2-4/52	S-4-11	1.7	23.0	4.8	2.7	2210	.07
			1.7	22.9	4.8	2.6	2260	.08
45	12/15-16/52	S-5-16	1.9	22.9	4.4	2.9	2640	.07
			1.7	22.6	4.6	2.9	2400	.08
46	12/18-19/52	S-2-9	1.6	22.6	4.7	2.9	2700	.10
			1.6	22.5	4.7	2.9	2690	.09
47	12/26-27/52	S-3-13	1.8	22.4	4.7	3.3	2550	.11
			1.8	22.5	4.8	3.3	2530	.11
48	12/29-30/52	S-1-13	2.0	22.6	4.8	3.3	2430	.12
			1.6	22.7	4.7	3.3	2360	.13
49	1/5-6/53	S-4-12	1.6	22.6	4.5	3.2	2510	.10
			1.8	22.7	4.5	3.2	2350	.10
50	1/21-22/53	S-2-10	1.7	22.7	4.9	3.3	2160	.12
			1.9	22.7	4.9	3.2	2160	.13
51	1/26-28/53	0-5-4	1.8	22.3	5.2	3.9	2080	.20
			1.8	22.2	5.2	3.9	2490	.19
52	1/19-20/53	S-5-17	1.8	22.8	4.8	3.0	2120	.09
			2.0	22.9	4.8	3.1	2080	.10
53	1/30-31/53	S-3-14	1.7	22.4	4.9	3.5	2550	.08
			1.8	22.3	4.8	3.6	2550	.17
54	2/4-5/53	S-1-14	1.8	22.9	5.0	3.2	2100	.13
			1.7	22.8	4.9	3.1	2090	.15
55	2/26-27/53	S-2-11	1.6	22.6	4.9	3.4	2210	.11
			1.5	22.6	4.7	3.4	2390	.13
56	2/28-3/1/53	S-3-15	1.4	22.7	4.9	3.6	2230	.14
			1.4	22.7	5.0	3.9	2180	.15
57	3/2-3/53	S-4-13	1.7	22.5	4.9	4.0	2100	.17
			1.5	22.6	4.9	4.1	1940	.19
58	3/6-7/53	S-1-15	1.7	22.5	4.7	3.3	2380	.12
			1.5	22.1	4.6	3.2	2540	.12
59	3/4-5/53	S-5-18	1.6	22.3	4.9	3.4	2230	.16
			1.8	22.2	4.9	3.6	2190	.17
60	3/18-19/53	S-2-12	1.7	22.9	4.8	3.4	1960	.12
			1.9	23.0	4.8	3.3	2000	.12
61	3/23-24/53	S-3-16	1.4	22.8	5.1	3.9	2060	.18
			1.6	22.7	5.2	3.9	2000	.18
62	3/25-26/53	S-4-14	1.7	22.3	5.3	4.0	2340	.22
			1.4	22.5	5.0	4.2	2100	.23
63	3/27-28/53	S-5-19	1.8	22.5	5.1	3.9	2060	.18
			1.7	22.6	5.0	3.9	1820	.20

Table 1 (Continued)

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave
64	3/30-31/53	S-1-16	2.0	22.1	5.1	4.1	2060	.26
			1.5	22.5	5.2	4.1	1840	.22
65	4/8-9/53	S-3-17	1.7	22.4	5.2	4.2	2100	.20
			1.8	22.5	5.2	4.1	1980	.19
66	4/2-3/53	S-2-13	1.7	22.5	5.2	3.9	2340	.19
			1.7	22.5	5.3	4.1	2220	.21
67	4/13-14/53	S-4-15	2.0	22.0	4.9	4.0	2540	.33
			1.7	22.1	4.8	4.6	2350	.31
68	4/15-16/53	S-5-20	1.8	22.0	4.9	4.1	2260	.32
			2.2	21.8	5.0	4.2	2380	.27
69	4/17-18/53	S-1-17	2.0	22.0	5.0	4.1	2480	.21
			1.7	22.4	5.1	4.1	2170	.25
70	4/27-28/53	S-2-14	1.8	22.2	5.1	4.1	2470	.23
			1.7	22.3	5.1	4.0	2360	.26
71	5/1-2/53	S-4-16	2.0	22.1	4.8	4.0	2530	.22
			1.8	21.9	5.0	4.1	2640	.20
72	5/5-6/53	S-5-21	1.7	22.1	5.3	4.4	2460	.29
			1.7	22.1	5.2	4.3	2480	.27
73	4/29-30/53	S-3-18	2.1	21.9	4.9	4.0	2610	.20
			2.0	21.9	5.2	4.0	2430	.21
74	5/8-9/53	S-1-18	1.6	22.2	4.9	4.3	2600	.28
			1.5	22.2	5.1	4.2	2740	.30

Table 2

CALCULATION OF F AND I FOR COMPOSITES

	SO_3	SiO_2	Al_2O_3	MgO	Auto-clave	7-Day Strength
r_1	0.6	0.6	0.7	0.6	.09	770
r_2	0.3	0.7	0.4	0.6	.05	420
r_3	0.7	1.4	0.6	1.3	.12	550
r_4	0.3	0.6	0.5	0.4	.08	390
$\sum_{i=1}^{4} r_i$	1.9	3.3	2.2	2.9	.34	2130
$\bar{r}_1$	0.475	0.825	0.550	0.725	0.085	532.5
$0.7025\bar{r}_1$	0.334	0.580	0.386	0.509	0.0597	374.1
Max. Spec.	2.0	----	6.0	5.0	0.5	-----
Min. Spec.	-----	21.0	-----	-----	-----	1500
F	1.7	21.6	5.6	4.5	0.44	1870
I	1.3	22.2	5.2	4.0	0.38	2250
r_5	1.0	0.9	0.4	0.5	.06	640
r_6	0.4	0.6	0.4	0.6	.06	620
r_7	0.4	0.6	0.7	0.9	.12	470
r_8	0.6	0.8	0.6	0.8	.14	420
$\sum_{i=5}^{8} r_i$	2.4	2.9	2.1	2.8	.38	2150
$\bar{r}_2$	0.600	0.725	0.525	0.700	.095	537.5
Ratio of $\bar{r}$'s	1.26	1.14	1.05	1.04	1.12	1.01

Table 3

CALCULATION OF $\bar{R}_1$, L, AND $\bar{R}_2$ FOR RANGE CONTROL CHARTS FOR COMPOSITES

	SO_3	SiO_2	Al_2O_3	MgO	Auto-clave	7-Day Strength
R_1	0.6	0.5	0.5	0.5	.08	520
R_2	0.4	0.1	0.5	0.5	.07	340
R_3	0.3	0.5	0.3	0.4	.05	420
R_4	0.1	0.5	0.4	0.3	.01	140
R_5	0.7	1.4	0.4	1.0	.04	550
R_6	0.2	0.9	0.2	0.3	.05	390
R_7	0.3	0.3	0.4	0.2	.07	240
R_8	0.1	0.7	0.2	0.2	.07	290
$\sum_{i=1}^{8} R_i$	2.7	4.9	2.9	3.4	0.44	2890
$\bar{R}_1$	0.3375	0.6125	0.3625	0.4250	0.0550	361.25
$L=2.282\bar{R}_1$	0.77	1.40	0.83	0.97	0.126	824
R_9	0.2	0.3	0.3	0.3	.05	320
R_{10}	0.6	0.5	0.3	0.5	.03	550
R_{11}	0.1	0.4	0.3	0.6	.06	280
R_{12}	0.4	0.5	0.4	0.4	.05	270
R_{13}	0.2	0.5	0.7	1.0	.11	430
R_{14}	0.4	0.5	0.1	0.4	.06	450
R_{15}	0.1	0.6	0.2	0.7	.05	420
R_{16}	0.6	0.7	0.2	0.2	.08	280
$\sum_{i=9}^{16} R_i$	2.6	4.0	2.5	4.1	0.49	3000
$\bar{R}_2$	0.3250	0.5000	0.3125	0.5125	0.06125	375.00

Table 4

COMPARISON OF BETWEEN AND WITHIN BIN VARIATION FOR INDIVIDUALS

Property	Source of Variation	Degrees of Freedom	Sum of Squares	Estimated Variance (or variation)
SO_3	Between Bins	25	1.15	0.0460
	Within Bins	26	0.56	0.0215
	Total	51	1.71	
SiO_2	Between Bins	25	4.423	0.17692
	Within Bins	26	0.365	0.01404
	Total	51	4.788	
Al_2O_3	Between Bins	25	1.71	0.684
	Within Bins	26	0.21	0.00807
	Total	51	1.92	
MgO	Between Bins	25	8.07	0.3228
	Within Bins	26	0.35	0.01346
	Total	51	8.42	
Auto-clave	Between Bins	25	0.20155	0.008062
	Within Bins	26	0.00955	0.000367
	Total	51	0.21110	
7-Day Strength	Between Bins	25	2,221,133	88,845.32
	Within Bins	26	351,950	13,536.53
	Total	51	2,573,083	

Table 5

TEST RESULTS FOR INDIVIDUALS

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave	A.P.F.*
1	1/4-5/52	S-1-2	1.4	22.9	4.9	3.4	1980	.15	3730 3900
2	1/21-22/52	S-4-2	1.1	23.0	5.0	3.3	1540	.20	3640 3940
3	2/7-8/52	S-1-3	1.6	22.6	5.2	3.6	1560	.25	4330 3790
4	1/25-26/52	S-5-7	1.2	23.0	5.1	3.4	1500	.18	3410 3630
5	3/3-4/52	S-4-3	1.2	23.0	5.2	3.5	1540	.19	3340 3380
6	3/12-13/52	S-5-8	1.8	22.3	4.7	3.0	2140	.10	3640 3510
7	3/25-26/52	S-1-4	1.4	22.3	4.6	3.0	1960	.13	3480 3520
8	4/2-3/52	S-4-4	1.6	22.2	5.0	3.4	2050	.12	3860 3610
9	4/11-12/52	S-5-9	1.2	22.2	5.0	3.8	1950	.17	3970 3630
10	4/28-29/52	S-1-5	1.5	22.5	5.0	3.2	2260	.10	3760 3570
11	5/14-15/52	S-2-2	1.4	22.7	4.5	3.3	2000	.16	3850 3380
12	5/26-28/52	0-1-3	1.7	22.8	4.2	3.1	2430	.11	3590 3740
13	6/4-5/52	S-4-5	1.3	22.9	4.6	2.9	2700	.14	3730 3630
14	6/9-10/52	S-1-6	1.5	22.8	4.8	2.9	2150	.13	3860 3570
15	6/12-13/52	S-5-10	1.4	22.7	4.6	3.0	2270	.13	3610 3500
16	6/23-24/52	S-2-3	1.6	23.1	4.3	3.2	2630	.11	3740 3590
17	6/30/7-1/52	S-3-7	1.6	23.1	4.3	3.2	2150	.15	3610 3470
18	7/14-15/52	S-4-6	1.9	22.3	4.8	3.9	1850	.14	3800 3480
19	7/17-18/52	S-1-7	1.7	22.6	4.8	4.2	1320	.26	4250 3940

* A.P.F. means A. P. Fineness

Table 5 (Continued)

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave	A.P.F.
20	7/30-31/52	S-5-11	1.3	22.5	4.7	3.6	2270	.15	3780 3410
21	8/4-5/52	S-2-4	2.0	22.1	4.4	3.1	2110	.11	3870 3850
22	8/6-7/52	S-3-8	2.0	22.2	3.6	3.2	2290	.09	4180 3840
23	8/13-14/52	S-1-8	1.8	22.7	4.2	2.7	2530	.06	3800 3980
24	8/18-19/52	S-4-7	1.7	23.0	4.3	2.9	2240	.09	3540 3670
25	9/2-3/52	S-5-12	1.6	22.4	4.6	3.3	2470	.11	3730 3570
26	9/4-5/52	S-2-5	2.0	22.3	4.5	3.0	2260	.08	3680 3530
27	9/11-12/52	S-3-9	1.9	22.9	4.8	3.2	2010	.12	3210 3840
28	9/15-16/52	S-1-9	1.9	22.9	5.1	2.9	2010	.17	3250 3490
29	9/18-19/52	S-4-8	1.9	22.4	4.8	2.7	2290	.17	3830 3790
30	9/29-30/52	S-5-13	2.0	22.5	4.8	2.9	2330	.05	3660 4010
31	10/1/52	S-2-6	1.8	22.2	4.8	2.9	2690	.20	3630 3890
32	10/3-4/52	S-3-10	1.4	22.7	4.9	3.0	2010	.14	3640 3640
33	10/7-8/52	S-1-10	1.7	22.6	4.9	3.0	2060	.17	3710 3830
34	10/7-8/52	S-4-9	1.7	22.5	4.8	3.1	2230	.14	3520 3530
35	10/22-23/52	S-5-14	2.0	22.7	4.8	2.5	1830	.12	4070 3960
36	10/23-25/52	S-2-7	1.8	22.7	4.6	2.6	2020	.11	3670 3990
37	11/1-2/52	S-3-11	1.7	22.9	4.5	2.8	2500	.10	3550 3500
38	11/3-4/52	S-1-11	1.6	22.4	4.5	3.0	2530	.09	4090 4300
39	11/5-6/52	S-4-10	1.8	22.2	4.3	3.1	2550	.07	4220 3820
40	11/11-12/52	S-5-15	1.6	22.3	4.7	3.5	1930	.12	3790 3730

Table 5 (Continued)

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave	A.P.F.
41	11/13-14/52	S-2-8	2.1	22.5	4.7	3.2	2270	.10	3500 3570
42	11/25-26/52	S-3-12	1.6	22.7	4.6	2.9	2560	.09	3940 3640
43	11/28-29/52	S-1-12	1.6	22.8	4.8	3.0	2220	.10	2600 3530
44	12/2-4/52	S-4-11	1.6	22.9	4.8	2.5	2310	.08	3590 3660
45	12/15-16/52	S-5-16	1.8	22.6	4.5	2.9	2820	.08	3800 3730
46	12/18-19/52	S-2-9	1.7	22.5	4.8	2.9	2430	.08	3790 3650
47	12/26-27/52	S-3-13	1.8	22.5	4.8	3.3	2280	.13	3980 3730
48	12/29-30/52	S-1-13	1.4	22.6	4.7	3.2	2620	.14	3640 3760
49	1/5-6/53	S-4-12	1.5	23.1	4.5	3.2	2420	.11	3610 3550
50	1/21-22/53	S-2-10	1.5	22.9	5.2	3.5	1990	.18	3600 3710
51	1/26-28/53	0-5-4	---	----	---	---	----	---	3450 3750
52	1/19-20/53	S-5-17	1.8	22.9	4.6	3.0	2140	.09	3480 3350
53	1/30-31/53	S-3-14	1.9	22.3	4.8	3.4	2650	.19	3450 3720
54	2/4-5/53	S-1-14	2.3	22.5	4.9	3.3	2550	.11	3370 3730
55	2/26-27/53	S-2-11	1.5	22.6	4.8	3.3	2360	.12	3300 3670
56	2/28-3/1/53	S-3-15	1.6	22.6	4.8	3.8	2480	.13	3200 3640
57	3/2-3/53	S-4-13	1.4	22.6	4.9	4.1	2210	.18	3440 3300
58	3/6-7/53	S-1-15	1.7	22.3	4.5	3.4	2660	.12	3550 3790
59	3/4-5/53	S-5-18	1.6	22.2	4.5	3.4	2640	.13	3440 3440
60	3/18-19/53	S-2-12	2.0	22.8	4.8	3.4	1960	.13	3390 3350
61	3/23-24/53	S-3-16	1.8	22.2	5.2	3.8	2080	.18	3460 3310

Table 5 (Continued)

Bin No.	Sample Date	Bin	SO_3	SiO_2	Al_2O_3	MgO	7-Day Str.	Auto-clave	A.P.F.
62	3/25-26/53	S-4-14	1.3	22.8	5.4	4.2	1850	.24	3530 3560
63	3/27-28/53	S-5-19	1.4	22.7	5.1	3.9	2020	.21	3440 3360
64	3/30-31/53	S-1-16	1.7	22.4	5.2	4.1	1960	.20	3330 3440
65	4/8-9/53	S-3-17	1.7	22.5	5.2	4.0	1970	.20	3640 3270
66	4/2-3/53	S-2-13	1.7	22.4	5.2	3.9	2090	.21	3460 3420
67	4/13-14/53	S-4-15	1.4	22.3	5.0	4.3	2160	.34	3570 3590
68	4/15-16/53	S-5-20	2.3	21.9	5.1	4.1	2370	.25	3670 3380
69	4/17-18/53	S-1-17	2.0	22.2	5.2	4.1	2310	.27	4030 3410
70	4/27-28/53	S-2-14	1.9	22.2	5.0	4.0	2390	.21	3280 3510
71	5/1-2/53	S-4-16	1.7	22.1	5.0	3.9	2630	.20	3520 3530
72	5/5-6/53	S-5-21	1.6	22.3	5.2	4.3	2480	.29	3690 3720
73	4/29-30/53	S-3-18	1.3	21.9	5.0	4.1	2240	.23	3650 3750
74	5/8-9/53	S-1-18	1.5	22.2	5.0	4.2	2770	.28	3480 3820

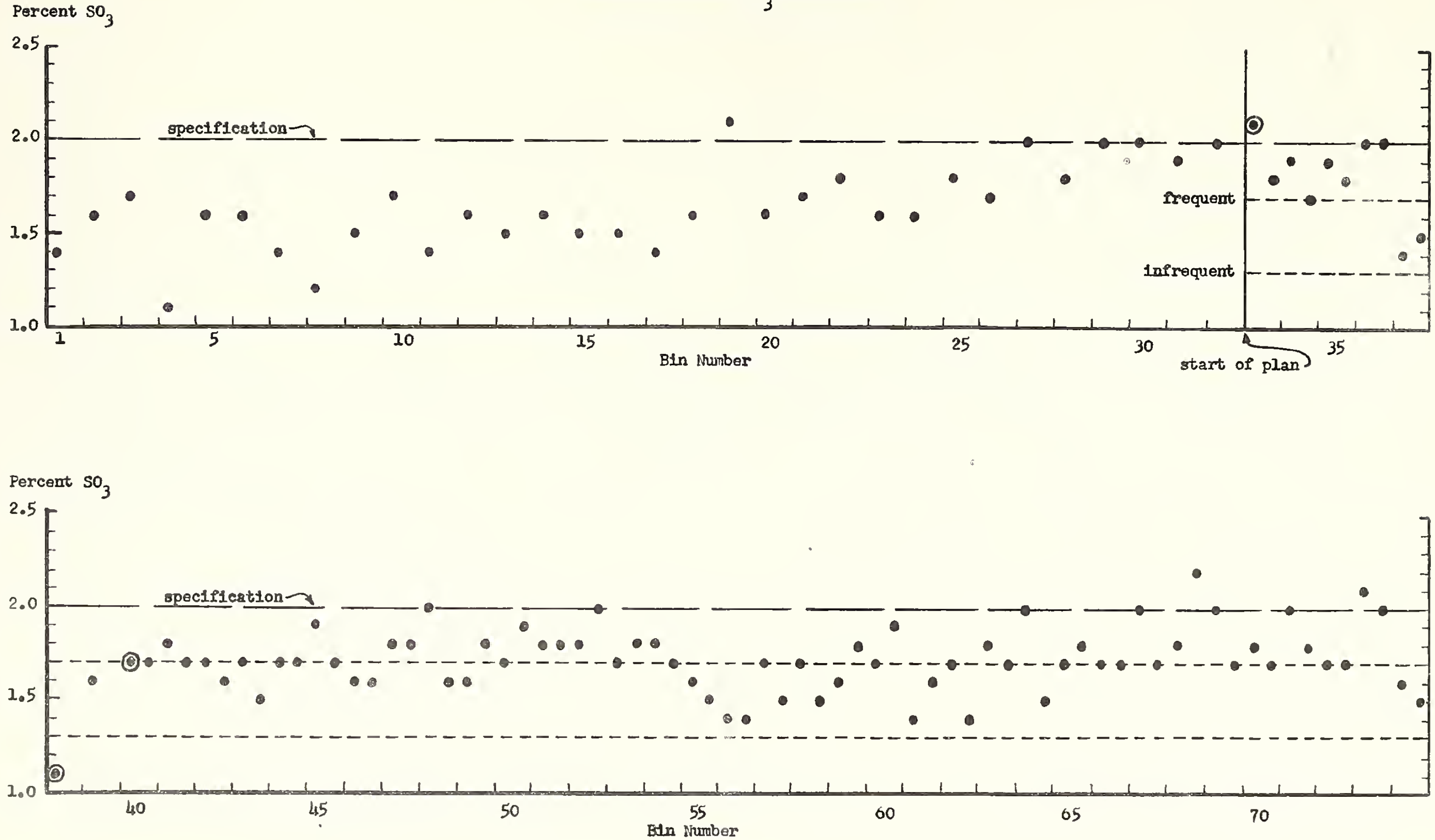
Table 6

CALCULATION OF F AND I FOR INDIVIDUALS

	SO_3	SiO_2	Al_2O_3	MgO	Auto-clave	7-Day Strength	A.P.F.
r_1	0.7	0.8	0.6	0.6	0.15	640	990
r_2	0.5	0.9	0.7	0.9	0.07	750	380
r_3	0.7	1.0	1.2	1.5	0.20	1210	710
r_4	0.6	0.7	0.6	0.6	0.15	680	620
$\sum_{i=1}^{4} r_i$	2.5	3.4	3.1	3.6	0.57	3280	2700
$\bar{r}_1$	0.625	0.850	0.775	0.900	0.1425	820	675
$0.7025\bar{r}_1$	0.439	0.597	0.544	0.632	0.100	576.0	474.2
Max. Spec.	2.0	-----	6.0	5.0	0.5	-----	------
Min. Spec.	----	21.0	-----	-----	-----	1500	3000
F	1.6	21.6	5.5	4.4	0.40	2080	3470
I	1.1	22.2	4.9	3.7	0.30	2650	3950
r_5	0.4	0.7	0.6	1.0	0.10	720	700
r_6	0.7	0.4	0.3	0.8	0.06	600	1380
r_7	0.9	0.8	0.7	1.1	0.10	660	410
r_8	0.7	0.6	0.9	0.8	0.12	810	220
$\sum_{i=5}^{8} r_i$	2.7	2.5	2.5	3.7	0.38	2790	2710
$\bar{r}_2$	0.675	0.625	0.625	0.925	0.095	697.5	677.5
Ratio of $\bar{r}$'s	1.08	1.36	1.24	1.03	1.50	1.18	1.00
F					0.43		
I					0.37		

Figure 1

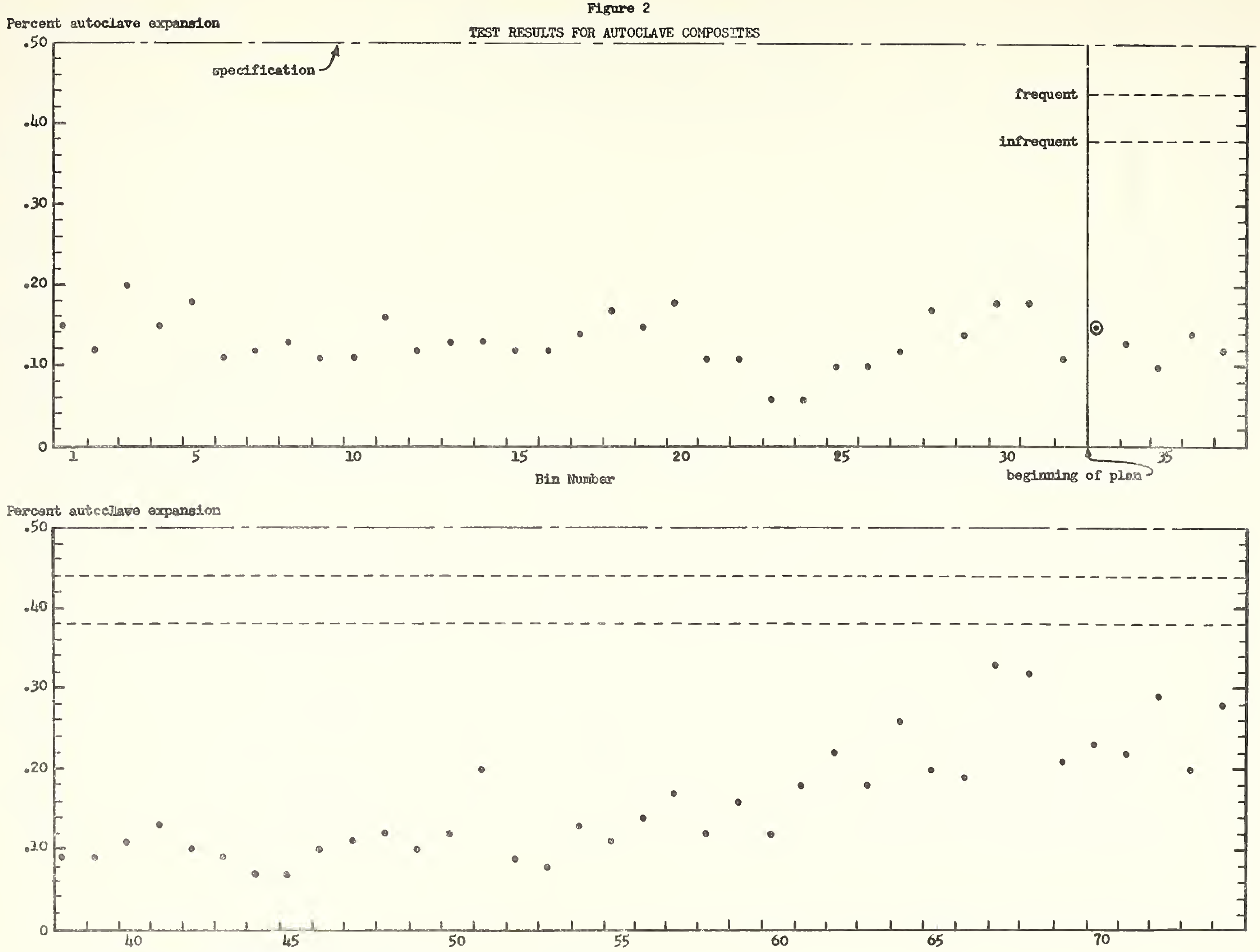
TEST RESULTS FOR SO_3 COMPOSITES



A circled dot, ⊙, indicates a sampling order.

Figure 2

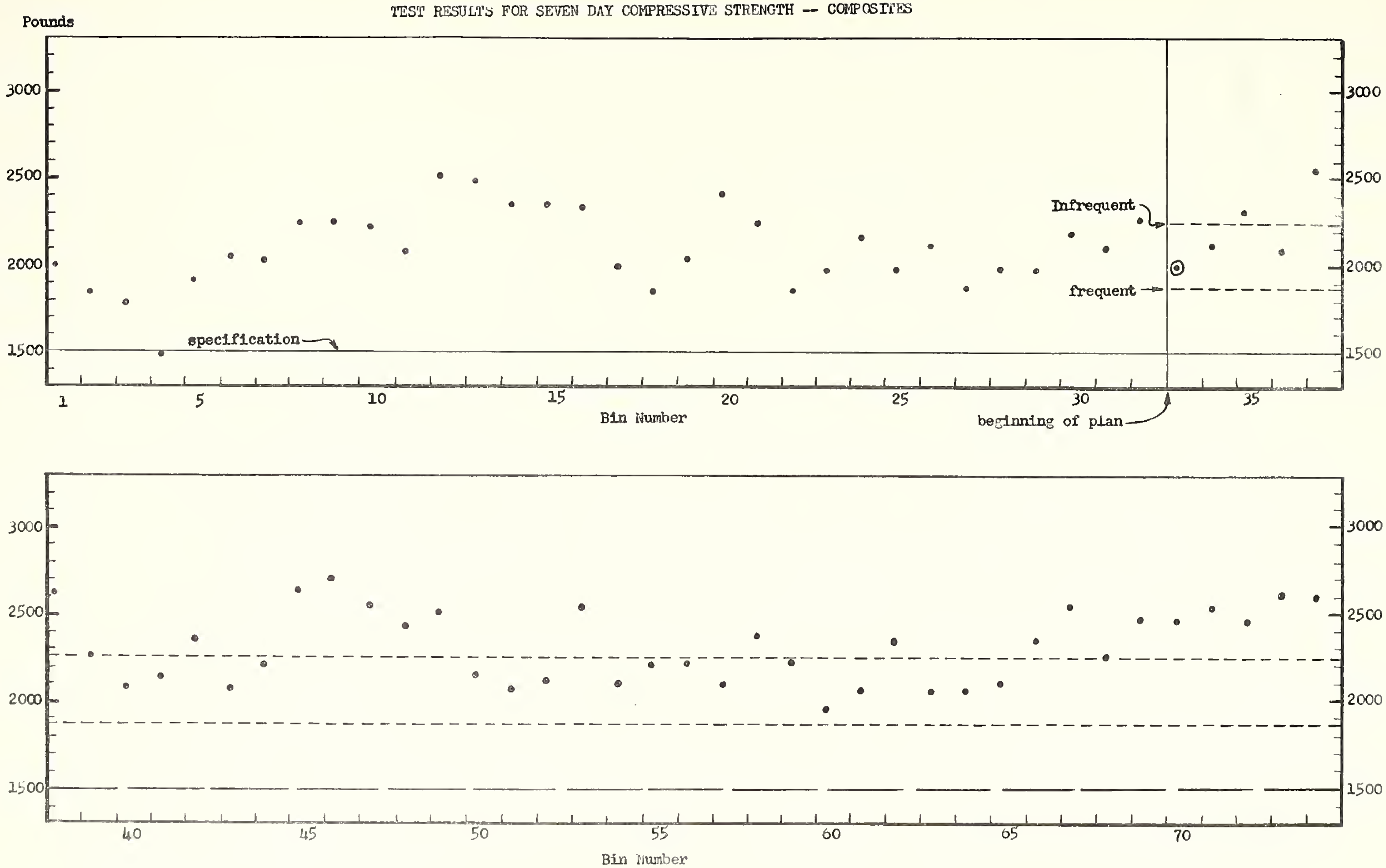
TEST RESULTS FOR AUTOCLAVE COMPOSITES



A circled dot, ⊙, indicates a sampling order.

Figure 3

TEST RESULTS FOR SEVEN DAY COMPRESSIVE STRENGTH -- COMPOSITES



A circled dot, ⊙ , indicates a sampling order.

Figure 4

RANGE CHARTS -- COMPOSITES

(Ranges for groups of 4 tests each)

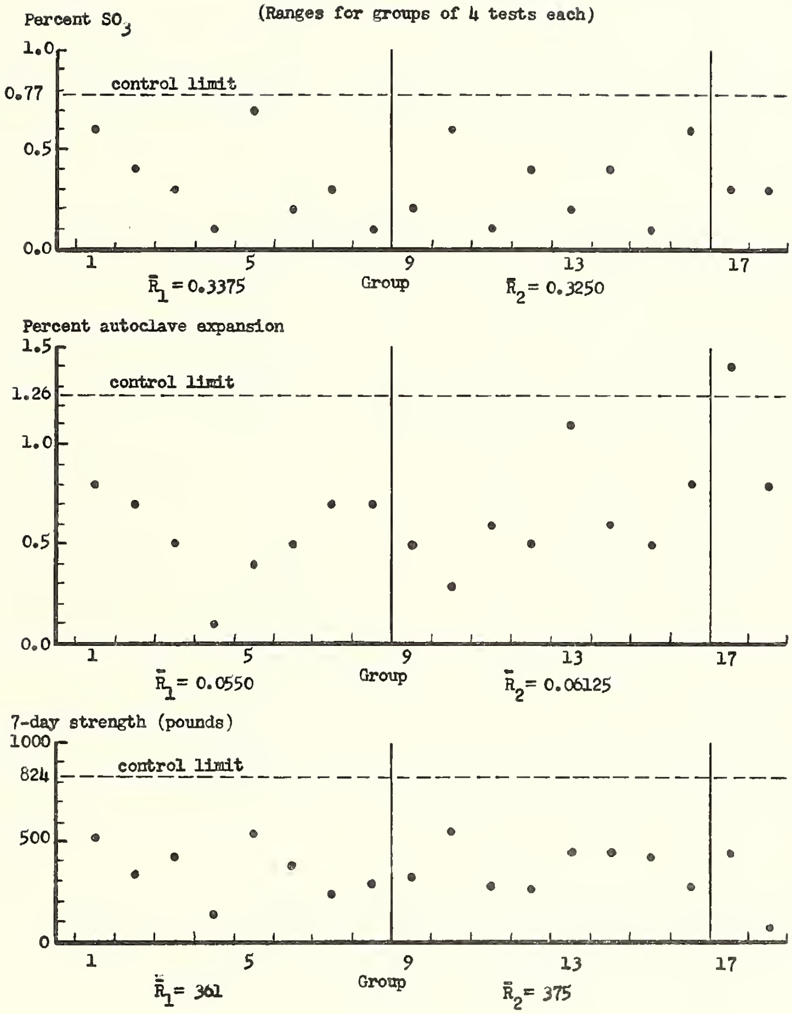
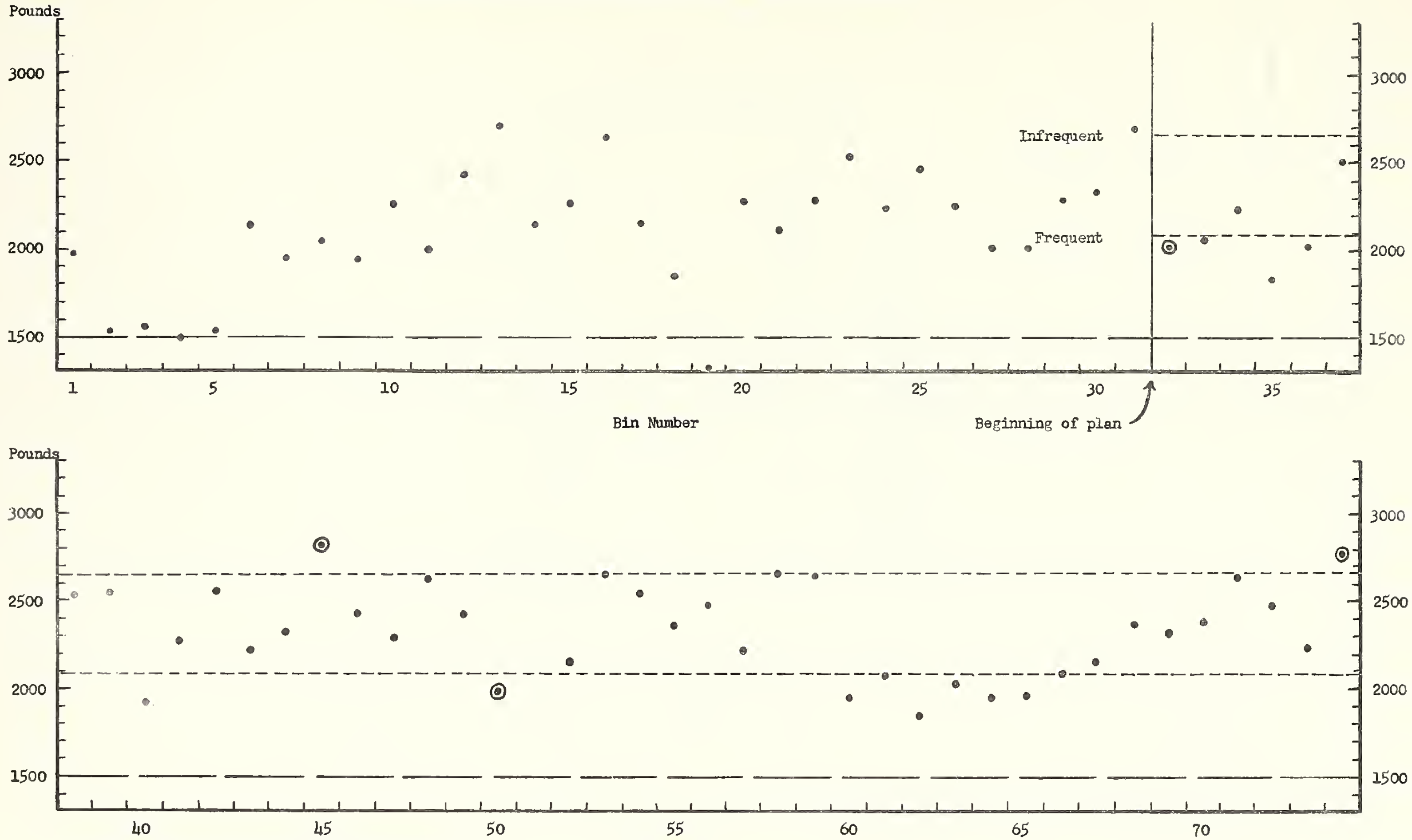


Figure 5

TEST RESULTS FOR SEVEN DAY COMPRESSIVE STRENGTH - INDIVIDUALS

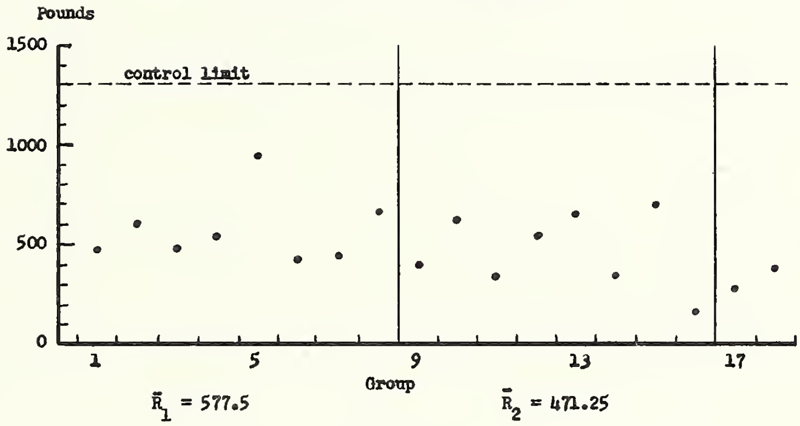


A circled dot, ⊙ , indicates a sampling order.
No sample was available for Bin No. 51.

Figure 6

RANGE CHART FOR 7-DAY STRENGTH-INDIVIDUALS

(Ranges for groups of 4 tests each)



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