Supplementary Study of 34-E Dual Drum Pavers

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This study supplements an investigation made in 1958 by 13 State highway departments and presented at the 1960 Annual Meeting. In preparing the earlier report, it was realized that the number of tests made per variable might have been insufficient to explore fully the suitability of mixing for only a short time. When this supplementary study was conducted, a greater number of strength specimens per variable of mixing time was made to obtain suitably complete data for short mixing times.

The results obtained in this study agree with the findings of the earlier report that concrete of adequate strength can be secured with a mixing time of less than 60 sec. When a mixing time of as few as 20 sec. was used, the concrete was found to have a strength at 28 days comfortably in excess of 3,000 psi. Although the concrete was harsh, the strength results for the different mixing times had an average coefficient of variation of 15.5 percent, indicating excellent control of the concrete.

• DURING the construction season of 1958, a study of 34-E dual drum pavers was conducted by 13 State highway departments. A summary report of the results of this study was prepared by the Bureau of Public Roads (1). In the preparation of this report, it was realized that the number of test specimens prepared per variable in each study by different State highway departments might have been insufficient to average out the uncontrollable variables such as the weather and the physical condition of the operators. It is believed that insufficient data for short mixing times have been obtained. The Arkansas State Highway Commission had planned to cooperate in this study, but delays in the grading and drainage of the selected project prevented placing the pavement in 1958. When the pavement was programed in 1960, the Commission offered to conduct a supplementary study to check the data obtained in the previous studies.

PROGRAM OF STUDY

Of principal interest was the preparation of a large number of concrete test specimens for each variable of mixing time. It was believed that more information could be obtained per man-hour if strength test specimens were limited to cylinders, consequently the preparation of beams for flexural strength tests was eliminated from the study. The outline of tests called for the use of only one overload of 20 percent, mixing times of 20, 30, 45, and 60 sec exclusive of transfer time, the preparation of 108 cylinders for each mixing time, and a suitable number of tests for consistency, air content, and unit weight. Due to excessive rainfall during the study, the number of specimens was reduced, and only 72 specimens were made for some mixing times. The specimens made were divided equally for tests at 7 and 28 days.

The study was made during the construction of Arkansas Project F-021-3(8) on a relocation of US 67 between North Little Rock and Jacksonville. As previously stated, heavy rainfall interrupted the study which began on June 21 and was completed July 21.

The mixer used was a Koehring 34-E dual-drum, built in 1958 and found to be in excellent condition. The equipment in the paving train included a spreader and vibrator, a finisher, a longitudinal float, and a jointing machine. The concrete pavement was covered for 24 hr with wet burlap and then sprayed with a pigmented curing compound. An average of 1,500 ft per 10-hr day of pavement 24 ft wide and 9 in. thick was placed.

The concrete was designed in accordance with the Arkansas specifications. The mix contained $5\frac{1}{4}$ bags of cement per cu yd, and a maximum water content of 5.5 gal per bag. The slump was specified to be approximately 2 in. and the air content between 3 and 5 percent. The aggregates used were natural sand and crushed stone from a local commercial producer. The mix proportions were 94-186-428 by dry weight. This resulted in only 30 percent of sand in the total aggregate on a solid volume basis, and furnished a harsh mix. However, as the concrete was vibrated, a satisfactory finish of the pavement surface was obtained.

Samples for testing were taken from the last batch of concrete placed on the subgrade before the paver backed to place the top course. Batches were sampled every 20 to 30 min. Approximately 2 to 3 cu ft of concrete were shoveled into a pan from five locations in the pile. The pan was carried to a truck and then taken to a sample preparation site established for each day's work.

It was planned to make tests for penetration by the Kelly ball, slump, and air by the Chace meter on every sample; then six 6- by 12-in. cylinders were cast. The Kelly ball tests were made on the bucket load of concrete on the subgrade, but the other tests were made at the sample preparation site. Tests for unit weight and determinations of air content by a pressure meter were scheduled to be made on alternate batches. The concrete cylinders were cast in cardboard molds with metal bottoms, and the completed cylinders covered with 5 layers of wet burlap. On the following morning, the molds were stripped, the cylinders marked, and then stored in tanks of water. The cylinders were taken to the State testing laboratory one day before the date of testing and were capped with a sulfur compound.

Timing of the mixing for the test batches was handled by personnel of the Construction Economy Branch of the Bureau of Public Roads. The contractor usually used a mixing time of 50 sec. However, he could not operate continuously at a fixed mixing time due to poor subgrade outside the forms. Batch trucks could not back to the skip, discharge, and clear the skip in the required time. Consequently, when time for a test batch approached, four consecutive batches were mixed the specified time and a sample taken from the last batch. For the mixing time of 20 sec, the paver was operated manually and only one batch was mixed at a time.

No appreciable difference in appearance was observed between the concretes mixed for different lengths of time and even with the 20-sec mixing the aggregate seemed to be well coated.

The study was interrupted by heavy rains when about one-half completed. When clear weather resumed, the grade beside the forms was so bad that trucks could not operate on it. The contractor tried double batching; that is, using two pavers, one on the service road and one on the grade. After a batch had been mixed dry in the first paver, it was dumped into the skip of the paver on the grade, and with the addition of water, mixed to form concrete. This procedure was conducted for only a few hours when the inspector closed the project due to spillage of materials. No specimens for this study were taken from the concrete prepared under these conditions. When construction was resumed about 3 weeks later, the study was completed without incident.

EFFECT OF MIXING TIME

Six cylinders were prepared from each batch of concrete tested. One-half of these cylinders were tested for compressive strength at an age of 7 days and the remainder at 28 days. Average values for the compressive strength of each group of 3 cylinders are given in Table 1 with information and data covering when the specimens were made, mixing time, air temperature, and consistency, air content, and unit weight of concrete.

The relation between mixing time and strength of concrete is shown in Figure 1. Of the two curves presented, greater weight is given to that for tests at an age of 28 days.

TABLE 1

SUMMARY OF TEST DATA

Mixing Time (sec)	Date	Hour	Air Temp. (°F)	Consistency (in.)		Air Content (%)		Unit Weight (pcf)	Average Compress. Strength (psi)	
				Kelly Ball	Slump Cone	Chace Meter	Press. Meter		7 Days	28 Days
60	6-21	2 45	-	-	4 0	6 0	-	-	2,620	3,320
		3 15	-	4 0	3.7	6 9	-	141	2,610	3,180
		4 00	-	1 5	2.5	4 7	3.8	-	4,040	4,940
		4 40	-	1 2	1 6	4.3	-	148	4,110	4,990
	7-20	9 00	88	2.0	2.5	5.2	3.8	-	3,440	4,150
		9·25	94	1.5	2.4	5.0	-	148	3,220	4,210
		9 45	94	1 8	1.6	4.0	3.9	-	3,590	4,370
		10 15	91	2.0	1 9	5.0	-	146	3,400	4,260
		10 35	98	1.4	1 5	5.0	4.0	-	3,730	4,760
		11 00	98	1.3	1 4	5.0	-	-	3,610	4,600
		11 20	92	1.0	1.9	4.0	-	150	5,190	6,230
		11:40	89	1.2	2.2	4.0	3.8	-	4,210	4,730
		Avg.	-	1.7	2.3	5.0	3 9	147	3,650	4,480
45	6-22	10·10	98	2.0	-	4 3	4.3	-	3,680	4,500
		10 55	98	2.8	2.6	5.2	-	144	3,190	3,950
		11 30	98	1.8	0.8	3 9	-	-	3,150	3,980
		11·55	99	2 8	3 8	6.0	4.9	-	2,770	3,800
		1 50	-	2.8	1.3	4 3	-	-	4,000	4,660
		2 20	99	2 0	1.5	5.6	-	146	3,440	4,420
		2 45	98	1.1	1.5	3.5	3.8	-	4,370	5,510
		3 15	98	1.9	0.3	4.7	-	146	3,420	4,100
		3 50	-	1 8	1 1	4.3	-	-	3,170	4,180
	7-20	1 20	85	1 5	2 5	4.7	5.2	-	3,840	4,700
		1·45	85	0 6	1 0	-	-	149	3,810	5,780
		2 00	83	1.0	0 9	3 5	2.7	-	3,930	5,410
		2 20	83	1 5	1.9	-	-	147	3,930	4,820
		2·35	82	2.0	2.6	2 7	3.2	-	3,560	4,660
		2·50	83	2.2	2.4	-	-	148	2,940	4,140
		3·10	85	0 7	0.8	-	-	150	4,730	6,060
		3 30	83	2.0	3.0	-	4.2	-	2,720	3,470
		Avg.	-	1.8	1.8	4.4	4.0	147	3,570	4,600
30	6-23	10 35	-	1.6	2 5	4.7	5.1	-	3,150	4,170
		11·00	-	1.6	1.2	4.3	-	145	3,150	4,200
		11 35	-	0.9	0.9	4.3	-	-	4,270	5,680
		11 55	-	1 3	1 7	4.3	3 9	-	4,280	4,450
		1 35	-	1.4	2 4	4.3	-	146	3,380	4,160
		2:10	-	2.2	2.5	4 3	-	-	3,480	4,600
		2·45	95	0.9	1.8	4.3	3.6	146	3,120	4,240
		3·15	96	2.0	2.5	4.3	-	-	2,620	3,440
		3·35	95	2.4	2.0	4.3	-	-	2,670	3,830
	7-21	9 30	92	1.2	2 0	6.4	4.8	-	3,220	3,800
		9·55	95	1.8	1.6	6.4	-	148	3,180	3,960
		10 20	94	1.4	1.5	6.0	3.3	-	3,960	4,410
		10 55	96	0.5	0.9	4.3	-	-	4,260	5,120
		11 10	86	1.2	0.6	4.7	3.1	-	4,480	5,600
		11 40	91	2.3	1.9	5.2	-	145	3,540	4,170
		Avg.	-	1.5	1.7	4.7	4.0	146	3,520	4,390
20	6-24	9 45	90	1 7	2.5	4.7	4.6	-	2,840	3,700
		10 15	90	2.4	2.5	3.5	-	146	2,990	4,160
		10 40	91	1.6	2.2	4.3	-	-	2,690	3,590
		11 00	86	1.6	2.2	3.9	4.4	-	2,470	3,290
		11 25	89	0.5	0.6	3.9	-	147	5,070	6,220
		11 45	78	2.0	3.4	4.3	4.3	-	2,760	3,610
	7-21	1 25	89	1 5	2 6	4.3	3.7	-	2,490	3,440
		1.45	86	1.5	2.0	5.6	3.8	-	2,710	3,250
		2·10	84	1.3	2.1	5.3	-	147	3,600	4,900
		2·25	81	1.0	1.7	3.9	-	148	4,280	4,360
		2:40	80	1.4	2.5	3.9	3.8	-	2,300	3,540
		2·55	78	2.2	1.5	3.1	-	149	4,160	4,900
		Avg.	-	1.6	2.2	4.2	4.0	147	3,200	4,100

This shows that the maximum strength is obtained with a mixing time of 45 sec. (All times excluded transfer time.) With the results for the 60-sec mixing time considered as unity, the strength ratios for the various mixing times are given in Table 2.

The results obtained here for mixing times of less than 60 sec are somewhat superior to those given in the report published in the April 1960 issue of "Public Roads." However both sets of tests demonstrate conclusively that mixing times of as few as 30 sec could be used with little reduction in strength. The small differences found between the sets of tests probably reflect the mechanical efficiency of the mixers used.

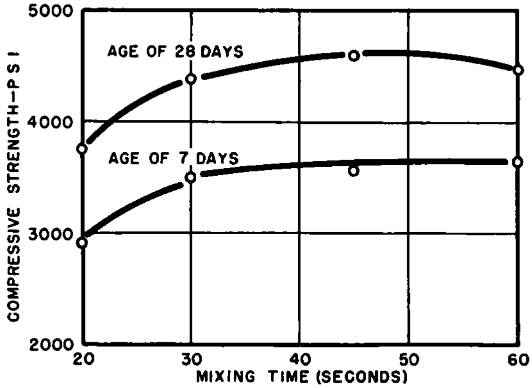

Figure 1. Effect of time of mixing on compressive strength.

VARIATIONS IN TEST RESULTS

The strengths obtained in tests of each individual group of cylinders at an age of 28 days are plotted in Figure 2. These data are presented to direct attention to some possibly unusual trends exhibited by specimens tested consecutively on the same day. One example is shown by the specimens representing 45-sec mixing time and starting with the 11th group. With one exception, the different groups of specimens show an almost uniform rate of loss of strength until this series of tests was completed. The exception concerns the next to last group of three specimens. This group has the highest compressive strength for any in this series of tests. The next and last group of the series has a low value agreeing with the general trend of the 11th to 15th groups.

Similar progressive increases or decreases of the test results can be seen in the plotted data for the other mixing times. For a mixing time of 20 sec, there are 2 sets of 3 groups of specimens which show uniform decreases in strength. The values for 30-sec mixing time show a set of 5 groups, the 10th to the 14th, with a fairly uniform rate of increase of strength. No marked changes similar to these were found for the specimens representing the 60-sec mixing time although the entire series of groups, the 5th to the 12th made on July 20, show with the exception of group 11, a slight but continual increase in strength. The group 11 shows wild results similar to certain single groups for each of the other mixing times.

TABLE 2

Mixing Time (sec)	Rel. Str. Ratio (%)
60	100
45	103
30	98
20	84[a]

[a]Six test specimens excluded (see discussion of Fig. 5).

The data collected during the course of this study fail to show any definite relation with all of the cases of progressive increase or decrease in the strength of all of the specimens previously mentioned. As mentioned later, available data correlate with one of these cases; however, with the others, some assumptions must be made.

With one exception, all of these progressive increases or decreases in strength occurred in July. The tests of the 60-sec mixing time were made during the morning

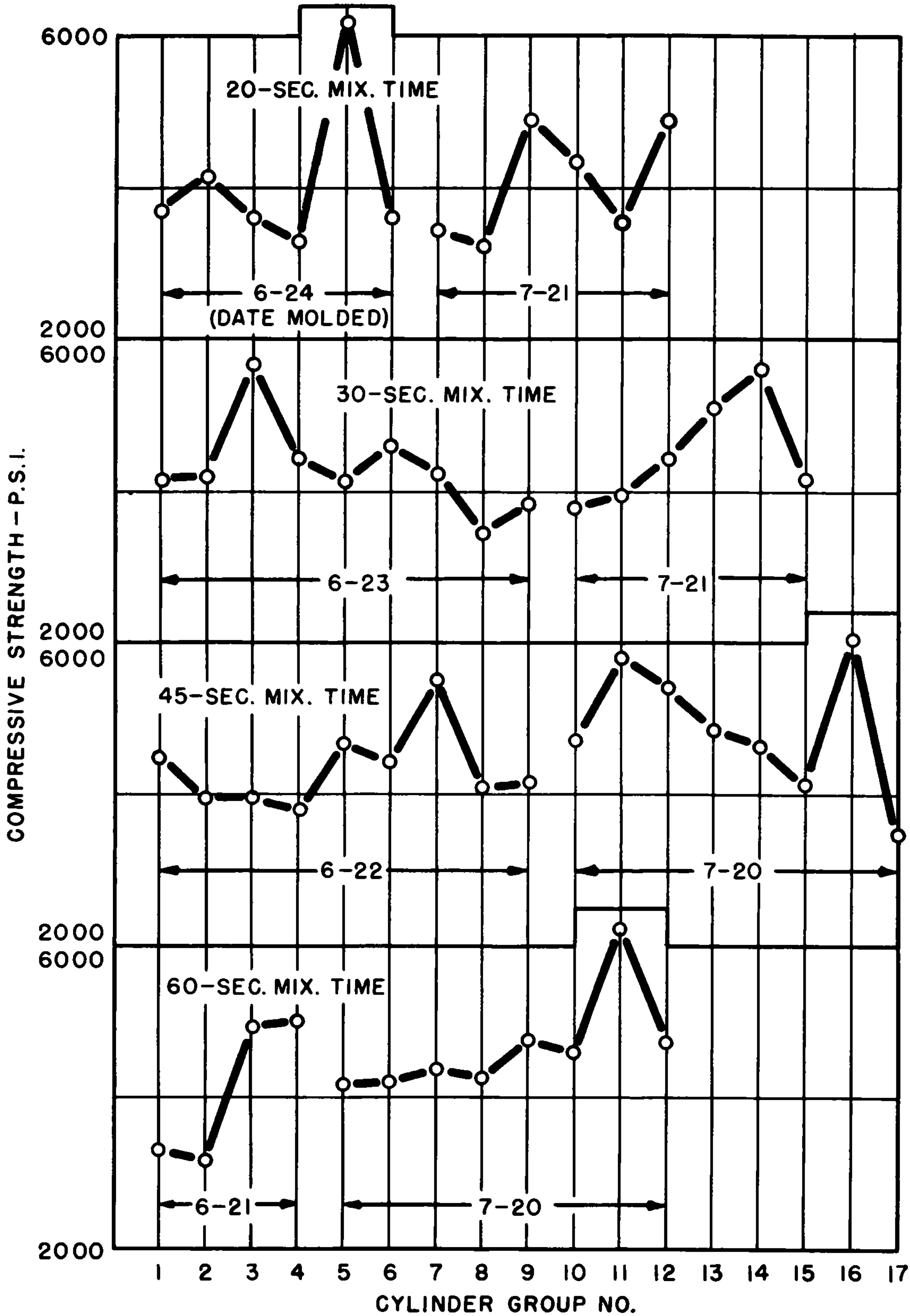

Figure 2. Strengths of groups of cylinders in order as molded; age of 28 days.

of July 20 and show, with one exception, rising strengths. During the afternoon of that day, tests were made with a mixing time of 45 sec. Six of the 8 groups of cylinders show progressively decreasing strength. On the following day, July 21, similar behavior was found. The tests of concrete prepared with a mixing time of 30 sec, which tests were made in the morning, show with one exception steadily increasing strength. Tests of the 20-sec mixing time made in the afternoon of July 21 gave confused results. Three consecutive groups of the six groups of cylinders did show steadily decreasing strengths, but the first two groups showed lower values, and the last a high value.

In attempting to explain unusual results of tests of concrete obtained in construction operations, writers frequently refer to items for which determined values are not available. The temptation to do that here is quite strong. Of all the various items that would have a marked effect on the strength of concrete and for which data are not available, first choice is given to the water content of the fine aggregate. Normal variations in this water content could be expected which might give the results mentioned. The receipt and use of a new lot of sand in a moist condition could cause the strength of concrete to decrease. Use of sand stockpiled and subjected to the high atmospheric temperatures shown for much of this study could cause the strength of concrete to be increased. However, in either case surplus or deficiency of water in the sand used should be reflected in changes in the consistency of the concrete.

Figures 3 and 4 show average values obtained in tests of concrete mixed for 20, 30, 45, and 60 sec, respectively. In each case, data are presented for compressive strength, Kelly ball penetration, slump, and air content by the Chase meter. In several cases data are not available, and the figure is so marked.

The average values for the 20-sec mixing time shown in Figure 3 do not disclose a reason for the two series of progressively decreasing strengths previously mentioned.

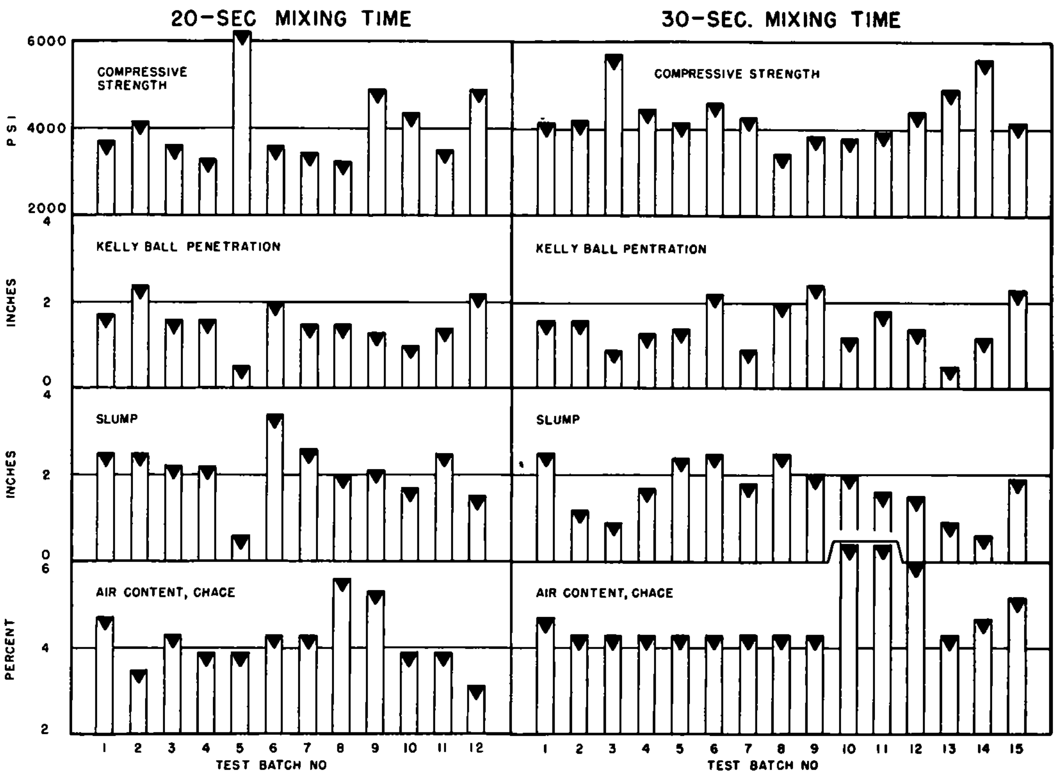

Figure 3. Average values determined from various tests on batches of concrete mixed for 20 and 30 seconds.

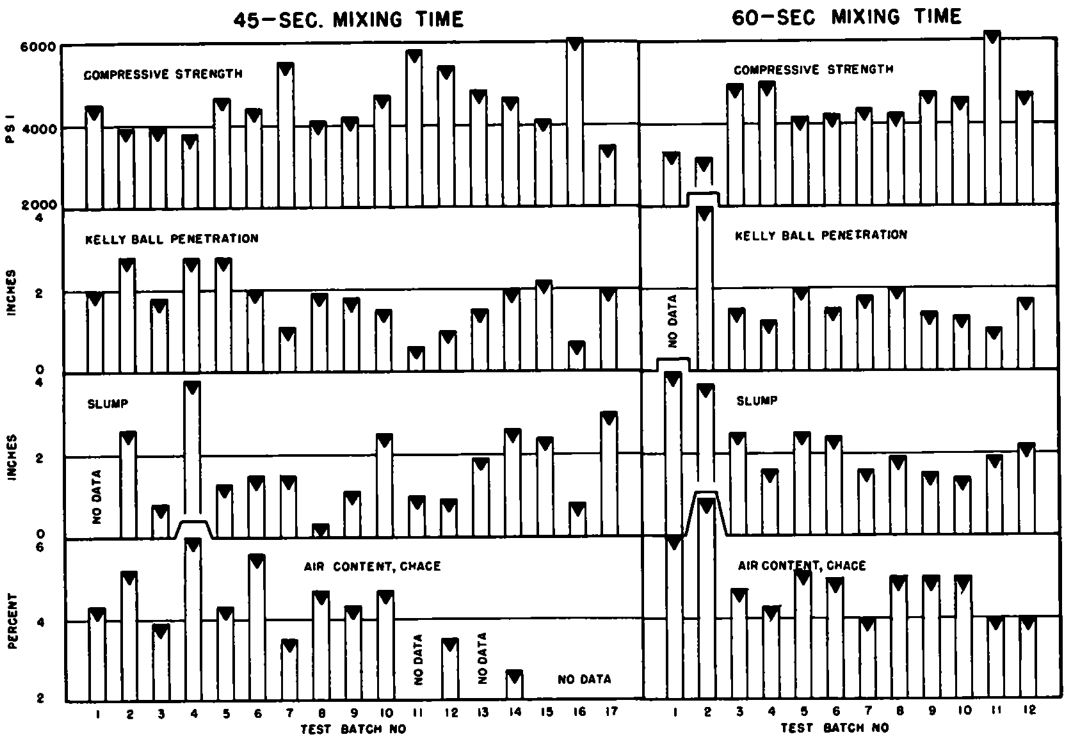

Figure 4. Average values determined from various tests on batches of concrete mixed for 45 and 60 seconds.

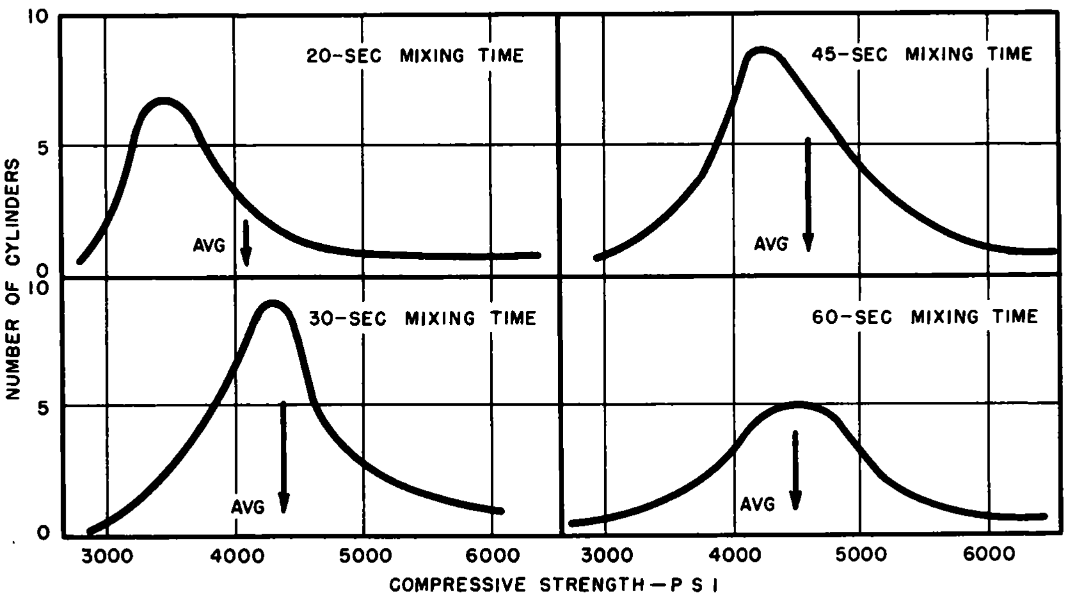

Figure 5. Frequency distribution of compressive strengths of concrete at 28 days.

On the contrary, the data obtained for consistency and air content of the concrete vary in a manner opposite to the trend of the results for strength. Little hope for an explanation of the performance of batches 2 through 4, and 9 through 11, is given here. The high strength of batch 5 is reflected however by the decrease in Kelly ball penetration and slump.

Information concerning the concrete produced with a 30-sec mixing time is also shown in Figure 3. This concrete shows high strengths for batches 3 and 14, and lowest strength for batch 8. Batches 10 through 14 show a set of continuously increasing strengths.

The records for slump of the concrete show for batches 10 through 14 a steady decrease which could well be associated with the increase in strength for these same concretes. The Kelly ball results for these batches are irregular, as are the determinations for air content. It seems to be somewhat questionable that a change in slump from 2.0 to 0.6 in. could cause a change in compressive strength from 3,800 psi to 5,600 psi. Possibly it would be proper to consider these slumps as indications that a change in consistency occurred which must have been accompanied by some other change to affect the compressive strength to such as extent.

The high strengths shown for batches 3 and 14, and the low strength for batch 8 are associated with low or high slumps, respectively. The results of the Kelly ball tests are of the same degree as those for slump, but not of similar magnitude.

Figure 4 for the concrete prepared with a 45-sec mixing time shows 3 batches with high or reasonably high strengths, and one low value. The highest value is an exception in a series of 7 batches which otherwise show a progressive decrease in strength. The first batch, No. 11 of this series, has a strength of 5,780 psi at 28 days, and the strengths decrease to 3,470 psi for batch 17. Kelly ball tests for batches 11 through 15 show a progressive increase in penetration, but the 16th batch has only a small value, and that for the 17th is only slightly above the average for all of the 45-sec tests. The slump of this 17th batch is of some magnitude, but the slumps for the other batches of this series are confused. No assistance in explaining the progressive increase in strength of this series of tests can be obtained from the Chace air determinations as so many of these tests were not made.

The tests of concrete prepared with a 60-sec mixing time (Fig. 4) fail to show other than a few correlations between strength and consistency or air content. Batches 1 and 2 have relatively low strength and high values for consistency. Batch 2 also has a high air content by the Chace meter. Batch 11 has the highest strength, but the determinations for consistency or air content fail to show any reason for this. Batches 5 through 10 show in general an irregular but small increase in strength from 4,150 to 4,600 psi. A somewhat similar decrease in slump is found for these same batches, but the Kelly ball and Chace air meter tests show no trends similar to those for strength.

In three of four cases, more definite correlation is found between the compressive strength of concrete and the slump than between the strength and either the Kelly ball or the Chace air meter determinations. This is somewhat of a disappointment. It had been hoped that the Kelly ball and Chace meter tests would correlate closely with strength tests of concrete. As these tests for consistency and air content can be made quickly, it was hoped that they could be used as acceptance tests with the definite knowledge of a close association with the strength of concrete. Such, however, is not found, and the slump test remains the more reliable indication of the quality of concrete.

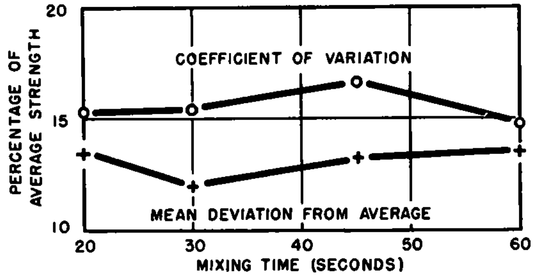

Figure 6. Comparison expressions for uniformity of compressive strengths of concrete.

CHACE AIR METER RESULTS

All of the tests for air content made with the Chace meter have an average value of 4.6 percent. This is sufficiently different from the average value of 4.0 percent obtained in tests with the pressure meter to warrant caution in accepting test results for the Chace meter. An air content of 4.0 percent is believed by many authorities to be about the least amount that will insure adequate resistance by concrete to the effects of freezing and thawing. Increase in the air content to 4.6 percent should be accompanied by a marked increase in the durability of the concrete. Consequently, the results obtained here with the Chase meter indicate for the concrete a durability that may be misleading. As mentioned by others in studies of the Chase meter, the test results obtained should be considered to indicate general ranges in air content—high, medium, or low. More precise indications should not be expected.

CONTROL OF CONCRETE

Abdun-Nur (2) in his paper on the probabilities of obtaining concrete of uniform strength, makes reference to the Bureau of Reclamation control of the strength of concrete. Under this control, a coefficient of variation of practically 15 percent is obtained. In the analysis of the data for the Arkansas project, it was decided to determine the coefficient of variation for each group of data and to compare the values obtained with those for the mean deviation from the average. This latter step was taken as the mean deviation is considered less difficult to compute and may be better understood by many engineers. In addition, frequency distribution curves were prepared from the test results for the specimens representing each of the four mixing times.

The frequency distribution curves are shown in Figure 5. It is seen that the curve for the 20-sec mixing time indicates that most values lie in a range from 3,100 to 4,300 psi. There are however some quite high test results which cause a marked misshape of the curve and a shift upward in the average value. In the interests of reliability of the findings of these tests, it might be appropriate to classify the six highest test results for single cylinders as sufficiently wild to warrant their rejection from the data considered. If this were done, the average value for the remaining test values would become 3,750 psi, a value more in keeping with the other findings of the study.

Although the curve for the 45-sec mixing time also shows a lopsidedness or skewness, the test data fail to show any particular point where higher values may be considered wild or unreliable. Consequently, no adjustment of the average value here is attempted.

Values for coefficient of variation and mean deviation from the average are plotted in Figure 6. The values for the 20-sec mixing time do not include the six wild results previously mentioned. Had these been included, the coefficient of variation would have been 21.8 percent, and the mean deviation from the average 17.2 percent. For the values presented, the coefficients of variation are close to the 15 percent mentioned by Abdun-Nur as denoting excellent control. Also, the mean deviation from the average follows closely the trend of the coefficient of variation.

From the frequency distribution curves in Figure 5, the most concordant test results were obtained with a mixing time of 30 sec.

In accordance with the requirements of their Standard Specifications, the Department drilled cores of the pavement for determinations of the thickness of the slab and the compressive strength of the concrete. The compression tests were made at an age of 3 months. For 59 cores tested an average strength of 4,430 psi was obtained, with

TABLE 3

CORE STRENGTHS

Mixing Time (sec)	No. of Specimens	Avg. Compress. Str. (psi)
20	2	3,760
30	3	4,180
45	4	4,060
60	3	4,530

maximum and minimum values of 6,060 and 2,410 psi respectively. Core strengths for the experimental sections of the pavement are given in Table 3. These values do not agree with those found in tests of the cylinders, but they do show that concrete of adequate strength was furnished even with a mixing time of only 20 sec.

Some concern has been expressed of the reason for the nonuniform results found throughout the study. As shown in Figure 5, values markedly different from the average occurred in the specimens prepared for each mixing time. The data associated with the strength results do not indicate why these variations were obtained. A review of data for the individual studies of mixing time conducted in 1958 generally showed more concordant strengths than those found in this study, but it was also observed that if the concrete was described as harsh, there was a tendency for a marked range in strength. The concrete used in this study was harsh, and it is believed that this harshness caused some exaggeration of the differences in strength normally found in tests of concrete. With a more plastic concrete, even lower values for coefficient of variation should be obtained than those reported here.

CONCLUSIONS

The results obtained in this study agree with the findings given in the earlier (1960) report to the effect that concrete of adequate strength can be secured with a mixing time of fewer than 60 sec, even including a mixing time of as few as 20 sec.

It is possible that the mechanical efficiency of the mixer used in this study permitted the attainment of better results for short mixing times than was found in the 1960 report.

For each mixing time used in this study, a considerable range in strength of concrete was found. Also for each mixing time, groups of specimens were found for which the strength of the concrete increased or decreased at a reasonably constant rate. It is possible that the harshness of the mix is responsible for some of the extreme test strengths obtained but no valid explanation for the progressive increase or decrease in strength of successive test batches is found from available data.

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