Mixing Time Requirements for Bituminous Mixes as Determined by the Ross Count Method

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During the 1963 construction season, tests were performed by the Materials Research Unit of the State Highway Commission of Wisconsin to determine the practicality of using the Ross Count Method of measuring aggregate coating in establishing a minimum wet mixing time for bituminous-concrete mixtures. The resulting effects of reduced mixing times on the mixture properties were measured by Marshall tests.

A preliminary study was conducted in the laboratory before beginning a field study which consisted of Ross Count and Marshall property tests on bituminous-concrete surface mixtures produced from six hot-mix batch plants. Crushed gravel aggregate was in four of the mixtures and crushed limestone in the other two. An 85-100 penetration grade asphalt cement was used in all mixtures.

Five samples were obtained and tested for Ross Count for any given wet mixing time and at least three wet mixing times were used at each plant. Duplicate Marshall specimens were formed in the field for each of three samples obtained for any given wet mixing time.

It was found that the Ross Count Method was a simple and practical procedure to use in the field with the reliability of results dependent on the experience and care of the operator. Ross Count test results show that the current State of Wisconsin specification of 45-sec minimum wet mixing time produced varying degrees of mixing completeness for each plant and mixture. However, an average trend for all mixtures showed nearly 100 percent aggregate coating after 45-sec mixing, and a reduction of mixing time reduced coating with the coating reduction becoming progressively more pronounced as mixing time was decreased.

Statistical evaluation of the test results indicate that the reliability of any one Ross Count decreases as the mixing time decreases. Thus, an increase in number of "counts" would be required for decreased mixing times to maintain a uniform degree of count reliability for all mixing times.

Marshall test results indicate that the mixture properties of all six mixtures were not significantly affected when the wet mixing time was reduced to permit 97 percent aggregate coating. It is concluded that the practical approach offered by the Ross Count Method could conceivably be used to establish and control satisfactorily minimum mixing time requirements. However, because the Ross Count is subject to numerous variables, it is desirable that the effects and control of these variables be studied to determine the full merit of the method as an adequate field control procedure.

•THE USE of an arbitrary mixing time specification for bituminous mixtures has been questioned by producers and highway agency personnel in recent years. The reason

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for concern is that factors other than mixing time may be important; thus, control of mixing should not be based on time alone.

Literature concerning the effect of mixing time was limited to studying the effect of mixing time on asphalt hardening prior to 1959. At the 1959 meeting of the Association of Asphalt Paving Technologists (AAPT) results of two investigations (1, 2) were reported which primarily considered the effect of wet mixing time variation on mixing completeness of bituminous mixtures.

One investigation (1) consisted of studying the efficiency of various pugmill mixers used to produce bituminous paving mixtures. Results of the study indicated random uniformity of aggregate gradation and asphalt distribution (not thorough coating) were completed before the coarse particles were coated. It was determined that the finer aggregate particles were coated before the larger particles; thus, it was proposed that "neither aggregate distribution nor sample to sample variation in A.C. content are controlling factors in time of mixing, but the coating of the coarsest aggregate particles in the mix may be."

During the course of the investigation (1), a method was developed, termed the Ross Count Method, which provided a simple means of numerically measuring the percent of coated particles. Essentially, the method consisted of obtaining a representative sample of bituminous mix as it was discharged from the pugmill mixer and separating the sample into coarse and fine fractions using a sieve of selected size. The coarse particles retained on the sieve were divided further by visually determining if each particle was completely or partially coated. The percent of coated or uncoated particles was computed on the basis of total number of coarse particles in the sample.

General conclusions of the other investigation (2) were that an adequate mixing time can vary with materials and mixers. The following conclusions were given as being applicable to any bituminous-concrete mixing process:

> 1. Random sampling techniques and appropriate control limits can be developed and applied to the mixing of bituminous concrete to serve as an evaluation of mixing efficiency.
> 2. Coating can be evaluated by visual methods. . . .
> 3. The methods of introducing materials and the characteristics of the pugmill are the most significant factors involved in the efficiency of the mixing process.
> 4. Bituminous-concrete mixers should be rated on their individual merits under the conditions that are imposed by a particular job in the field. A blanket mixing time specification cannot logically be applied to all mixers.

These two studies led to an increased interest in determining a satisfactory mixing time based on an actual test measurement rather than an arbitrarily selected period of time. Both studies indicated that coating of aggregate, a measure of mixing completeness, can be evaluated by visual methods. The Ross Count Method is the simplest method proposed to date and has been used recently by several highway agencies to study the usefulness of the method for adjustment of mixing time. Results of these highway agency studies are not presently available, but there are indications that some of the agencies involved are considering adoption of a count method. There are those, however, who argue that film characteristics are much more important than coating of the larger particles in obtaining desired mix properties. Others have suggested that the foremost requirement is to obtain an equilibrium of distribution of asphalt and aggregate.

The discussion of a progress report on the Ross Count Method (3) presented results of studies by the Bureau of Public Roads which showed that uniformity of asphalt and aggregate distribution did occur before complete coating of the larger particles for dense graded mixtures. However, tests made with open graded mixtures indicated 98 percent coating of the larger particles was obtained before uniformity of material distribution was achieved.

From the information presently available on the effects of time on mixing of bituminous-concrete mixtures, and from the above discussion, it is apparent that a thorough mixing time study cannot be made using one asphalt, aggregate and pugmill mixer. Therefore, a mixing time study, utilizing the Ross Count Method, which would encompass various types of asphalts, Wisconsin aggregates and mixers was conducted during the later part of the 1963 construction season.

PURPOSE AND SCOPE

Because previous experience with the Ross Count Method was lacking, a laboratory study was conducted to acquaint personnel with the method and to develop procedures before beginning the field phase of the study program. The ability of one operator to reproduce the "count" of another operator (reproducibility) was investigated during the laboratory phase. The information gained from the laboratory work served as a guide for the sampling and testing procedures used in the field.

One objective of the field study was to obtain information about variations in coating of the aggregate which could be expected at different mixing times for various pugmill mixers and types of asphalt and aggregate. Determination of variations in Marshall properties of the mix due to changes in mixing time was a second objective of the field phase. The two objectives were accomplished by conducting a series of Ross Count tests for various mixing times at six different batch-type bituminous mix plants. It was intended that the data obtained would also be used for a statistical analysis of the variations which occurred for various conditions.

The type of mixtures used for both phases of the study was surface course mix (Gradation No. 3, Section 401.2.5 of the Wisconsin Standard Specifications, 1963). This mix type limitation permitted sufficient data to be obtained for a comparison of the various mix plants involved.

The procedures and discussion of test results are treated separately for the laboratory and field studies of the investigation.

LABORATORY ROSS COUNT STUDY

Material and Equipment

Asphalt and aggregate materials remaining from samples submitted for routine laboratory bituminous mix designs were used in the laboratory phase of the test program. The use of materials previously processed by the mix design laboratory gave the advantage of selecting designs having predetermined aggregate gradation and

TABLE 1

LABORATORY MIXTURE INFORMATION
(Percent Passing Sieve)

Sieve Size	Mixture A[a]		Mixture B[b]		Mixture C[c]		
	Crushed Stone	Sand	Crushed Gravel	Sand	Crushed Stone	Stone Chips	Torpedo Sand
3/4 In.	100	-	-	-	-	-	-
1/2 In.	95	-	99	99	100	-	100
3/8 In.	80	100	87	98	99	100	99
No. 4	54	99	64	97	68	56	91
No. 8	40	94	-	-	45	9	79
No. 10	-	-	49	95	-	-	-
No. 40	-	-	22	89	-	-	-
No. 50	22	7	-	-	15	4	44
No. 80	-	-	8	64	-	-	-
No. 200	10.8	1.9	5.6	42.4	11.2	3.0	10.0

[a]Crushed limestone with blending sand: crushed stone-90%; sand-10%; asphalt content-5.6%.
[b]Crushed igneous and limestone gravel with blending sand: crushed gravel-91%; sand-9%; asphalt content-5.8%.
[c]Crushed limestone with blending sand: crushed stone minus 3/8 in.-30%; stone chips-30%; Torpedo sand-40%; asphalt content-6.1%.

asphalt content data. Three designs were selected from the limited number of retained samples to provide two types of aggregate mixtures: crushed limestone and crushed gravel. The three selected mix combinations are given in Table 1.

A modified Hobart electric mixer was used for mixing. The hot mix was separated into fine and coarse particles on a 1/4-in. sieve. The sieve was 17 in. in diameter with a 3 3/4-in. wooden sidewall.

Test Methods

Aggregate batch sizes were controlled to provide at least 250 coarse particles on the separating sieve. Thus, the batches ranged from 2,000 to 3,500 gm, depending on the aggregate gradation. The asphalt content at the peak of the mix design density curve was selected for each mixture.

Aggregate batches were heated in a gas-heated oven to temperatures ranging from 325 to 390 F. The aggregate was placed in the mixing bowl and the desired amount of asphalt was added to the mixing bowl which was placed on a 1-gm direct-reading scale.

A 2-min wet mixing time has been adopted by the bituminous mix design laboratory to obtain satisfactory mixing of asphalt with a 2,500-gm batch of aggregate using the Hobart mixer. Therefore, 2 min was chosen as a control mixing period for the laboratory study. Changes in mixing time were in 1/2-min increments and at least three batches were tested for each mixing time.

Preliminary to beginning the laboratory testing program, several trial samples were mixed, separated and counted to check procedures and make any changes deemed necessary. The first batches were separated on a No. 4 sieve resulting in retention of particles believed to be too small for convenient counting. The minimum size particles retained on a 1/4-in. sieve, however, were found to be satisfactory for counting. Thus, the 1/4-in. sieve was chosen as the separating size for use throughout the study.

Early in the laboratory work it was apparent that the operators processed four or five counts before they were confident of their results. Confusion existed during the initial counting as to what should constitute an uncoated particle. Although most particles were either definitely coated or had definite breaks in surface coating, there were a small number which appeared to have discolored surface areas without an asphalt film. Several of these questionable particles were washed with a degreasing solvent and it became evident that a thin film of asphalt was present. Thus, only those particles which had a definite break in surface coating and/or discoloration were considered to be uncoated.

The initial results indicated that mixing temperature affected the degree of aggregate coating. Therefore, observations of temperatures were recorded for asphalt and aggregate just prior to mixing and for the final mix immediately after mixing. Variations in temperatures of the individual materials undoubtedly had some effect on the coating of particles. Thus, mixes with the same temperature after mixing may have differed in the individual asphalt and aggregate temperatures prior to mixing, resulting in different degrees of coating.

Although the main objective of the laboratory study was to familiarize the operators with procedures of the Ross Count Method, a study of reproducibility of counts was also included to determine the reliability of the method. (Reproducibility refers to the agreement of the count of one operator with the count of another operator for a given sample.) The procedure was as follows:

1. The coarse particles of a mix (those particles retained on the 1/4-in. sieve) were split into two samples by quartering.

2. Each split sample was counted by one operator. For example, split sample 1 was counted by operator 1 and split sample 2 was counted by operator 2.

3. Following the original count (separation of coated and uncoated particles), particles of each split sample were recombined and counted by the other operator. For example, split sample 1 was counted by operator 2 and split sample 2 was counted by operator 1.

TABLE 2

LABORATORY ROSS COUNT DATA SUMMARY

Laboratory Mixing Time (min)	Operator	No. of Split Samples Counted[a]	Temperature (F)			Total No. of Particles	Percent Uncoated Particles	Average Percent Uncoated Particles
			Asphalt	Aggregate	Mixture			
Mixture A								
1½	1	4	285	350	255	324	44.2	
	2	4	285	350	255	336	43.1	43.7
2	1	6	285	375	275	352	33.5	
	2	5	285	370	275	337	32.8	33.2
Mixture B								
1½	1	7	285	390	310	280	12.8	
	2	7	285	390	310	281	12.1	12.5
2	1	5	280	390	290	279	8.8	
	2	5	280	390	290	283	8.0	8.4
2½	1	4	280	380	280	308	4.4	
	2	4	280	380	280	308	4.0	4.2
3	1	10	280	365	270	325	4.4	
	2	10	280	365	270	325	4.2	4.3
3½	1	8	280	365	260	307	3.4	
	2	8	280	365	260	307	3.5	3.5
Mixture C								
¾	1	1	-	-	-	622	18.0	
	2	3	-	-	-	573	15.8	
	3	3	-	-	-	572	14.5	15.6
1	1	1	-	-	-	289	9.0	
	2	5	-	-	-	562	10.1	
	3	5	-	-	-	605	9.4	9.7
1½	1	1	-	-	-	216	4.6	
	2	1	-	-	-	555	7.8	
	3	1	-	-	-	349	8.3	6.9

[a]Two split samples equal one mix.

Test Results

Ross Count test data are summarized in Table 2 for the laboratory mixed samples. Only mixture B offered sufficient retained material to provide an adequate number of counts for analysis at various mixing times. Although the results for mixtures A and C are incomplete in themselves, with respect to number of counts for each mixing time, they do serve to substantiate the results for mixture B.

A plot of average Ross Count values at various mixing times for each mixture resulted in the general trend curves shown in Figure 1 which illustrate that the percent of uncoated particles decreased as mixing time increased. It is apparent from Figure 1 that the rate of decrease in percent of uncoated particles will vary for changes in aggregate gradation and asphalt content. The curves of Figure 1 also suggest that the percent of uncoated particles can be expected to vary at any given mixing time due to variations in aggregate type and gradation, and asphalt type and content.

Warden, Ward and Molzan (3) suggest that the relationship of percent uncoated particles and mixing time is represented by an exponential function which plots as a straight line on semi-log paper within the range of 0 to 40 percent uncoated particles. A plot of this type is shown in Figure 2 for mixture B to demonstrate that a straight line is a good indication of the trend of the relationship. The results at the 2½-min mixing time period obviously do not follow the straight-line trend; however, an increased number of counts at this particular mixing time may have given an average value more in line with the majority of the test results.

Table 3 gives the difference between percent uncoated particles or Ross Count values obtained by two operators for a given sample. The average difference for each of the three mixtures was less than one percent, and a combination of the average mixture values resulted in an overall average difference of 0.64 percent. Apparently the operators were assessing the degree of coating on an essentially equal basis, and close agreement of the laboratory counting results provided assurance that field counts would be reliable regardless of which operator made the count.

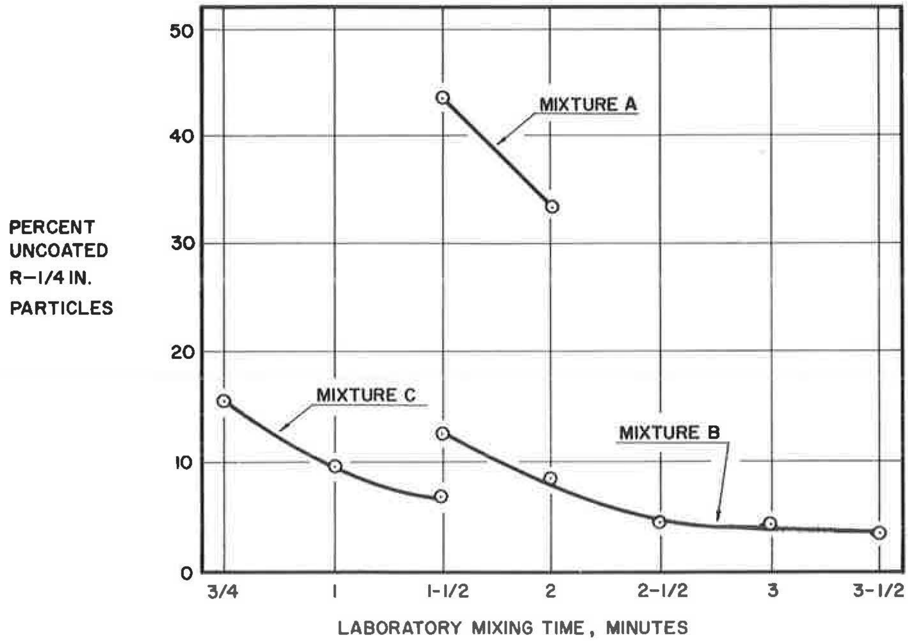

Figure 1. Coating of coarse particles vs laboratory mixing time.

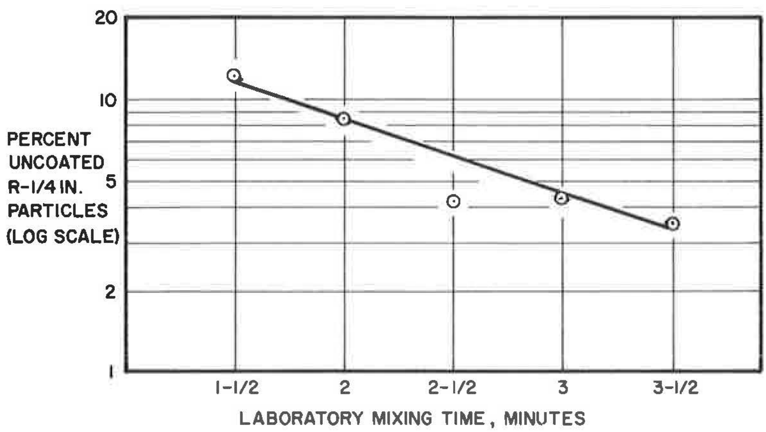

Figure 2. Coating of coarse particles vs laboratory mixing time, mixture B (semi-log plot).

A statistical analysis of the data of Table 3 indicated the differences in count values obtained by two operators for a given sample were significantly different at a 5 percent level of significance, implying there is evidently a systematic difference between the results not due to change alone. It is reasonable to assume the differences in count results are due to the individual bias of operators. It is apparent that operator 1 usually counted more uncoated particles than operator 2, and this observation was reflected in the statistical inference. Bias between operator 2 and 3 was not apparent in the results, as reflected in the statistical acceptance of the hypothesis that no significant difference existed between counts for mixture C. Generally, the statistical

TABLE 3

LABORATORY STATISTICAL DATA SUMMARY

Mixture	Laboratory Mixing Time (min)	No. of Counts	Avg Percent Uncoated R¼-In. Particles			Counting Difference and Std. Dev. (%)
			Operator 1	Operator 2	Operator 3	
A	1½	2	36.9	36.1		0.8[a]
	2	5	33.5	32.8		0.7[a]
						0.83[b]
						0.67[c]
B	1½	6	14.1	13.2		0.9[a]
	2	4	7.3	7.2		0.1[a]
	2½	4	4.4	4.0		0.4[a]
	3	4	2.7	2.4		0.3[a]
	3½	6	3.5	3.6		0.1[a]
						0.51[b]
						0.52[c]
C	1	4		11.0	11.2	0.2[a]
	¾	2		23.3	21.5	1.8[a]
						0.92[b]
						1.12[c]
Overall						0.64[d]
						0.76[e]

[a] Average counting difference.
[b] Average mixture counting difference.
[c] Estimated mixture standard deviation of difference.
[d] Overall mixture counting difference.
[e] Overall estimated standard deviation of difference.

results do not imply that the counting differences are large, but only that the occurring differences are systematic implying that a counting bias existed for operators.

One variable observed to have considerable effect on coating of particles was mixture temperature during the mixing operation. The equipment available at the time the laboratory work was in progress did not permit control of temperatures to the extent desirable or necessary to demonstrate the effect fully. Differences in average count values for mixture B after three minutes mixing serve to illustrate the effect of mixing temperature: The average percentages of uncoated particles for the three mixtures were 4.0, 2.7 and 2.4 for mixing temperatures of 275 F and above, but increases to 5.5 and 6.8 were recorded when the mixing temperatures were decreased to 250 F or below. Variations in viscosity of the asphalt cement due to changes in mixing temperature offer a reasonable explanation for the differences of coating noted for any given mixing time.

FIELD STUDY

The field program was conducted to determine the magnitude of variations in coating of aggregate, as measured by the Ross Count Method, for various mixing times, pugmill mixers, and types of asphalt and aggregate. Tests were performed, also, to determine the effect of mixing time variation on Marshall test properties of the mixes.

Test Variables

The study was limited to six plants producing surface mixtures using 85-100 penetration grade asphalt cements. All bituminous plants were the batch type.

Although many variables were eliminated by the above limitations, the study involved several other factors which may or may not have affected results. The following list of possible variables of the study is suggested:

1. Plant operating mechanism, especially the pugmill type and condition.
2. Mixture variations of asphalt and aggregate materials regarding type, proportioning and quantity.

3. Temperatures of the asphalt in the surge tank, aggregate in the hot bins, and mixing temperature of the combined materials.
4. Operator error resulting from work (sampling, particle counting and Marshall specimen compaction) by six operators.
5. Effect of climate or weather conditions on mix materials, such as the effects of rain on the aggregate stockpile and humidity at the time of mixing and counting.

In addition to the suggested variables, there are inherent and unavoidable variations due to sampling. It is significant, also, that test data accuracy and reliability are only as dependable as the test itself. The Ross Count Method is simple, and to some degree practical, but empirical since it is based on assumptions and involves a "human error" or bias. The errors involved in the Marshall tests are variable depending on conditions such as compaction, number of replicate specimens, and degree of care exercised in handling, curing and actual performance of the various tests.

Materials and Mixtures

Table 4 gives materials and mixture data for the six mixes studied. The data were obtained from laboratory mix design reports for each project. Crushed gravel aggregate was used for four mixtures and crushed limestone for two. Los Angeles wear losses for the two limestone aggregates were high, and aggregate sodium sulfate soundness for mixture 5 was high at 19.6 percent loss after 5 cycles. All mixtures were composed of similar aggregate gradings, so much so that aggregate gradation may not have been a significant variable of the study. The recommended asphalt content range of mixture 6 is high when compared with asphalt content ranges normally recommended.

Plants and Pugmill Mixers

Table 5 gives available data on the plants, plant components, control features, and operating conditions. Pugmill mixer conditions were generally good, as rated visually. All but one plant measured asphalt by weight and all plants were equipped with a time control switch. Pugmill mixing periods for the dry aggregate ranged from 0 to 8 sec and averaged about 5 sec.

TABLE 4

FIELD MATERIALS AND MIXTURE INFORMATION

Item	Mixture					
	1	2	3	4	5	6
Aggregate characteristics						
Type	Gravel	Gravel	Limestone[a]	Gravel	Gravel[b]	Limestone[c]
Fractured particles, %	74	88	98	74	65	99
L. A. wear loss, %	32	21	47	39	28	51[d]
Sodium sulfate soundness loss after 5 cycles, %	10.5	0.9	12.4	11.8	19.6	12.8
Passing sieve size, %:						
¾ In.	100	100	100	100[e]	100	100
½ In.	98	98	95	99	96	99
⅜ In.	83	86	81	88	85	86
No. 4	62	64	60	64	63	59
No. 8	50	51	47	-	52	46
No. 50	19	16	21	-	22	23
No. 200	8.7	6.7	9.3	9.2	9.0	7.5
Asphalt cement						
Pen. grade	85-100	85-100	85-100	85-100	85-100	85-100
Mixture features						
Recommended asphalt content range, %	4.8-6.5	5.4-6.6	5.1-7.1	5.1-6.2	6.0	7.4-8.8
Recommended pugmill mixture temperature range, F	270-300	275-305	265-305	265-295	285	265-305
Maximum compacted laboratory density, pcf	155.4	149.8	152.9	152.6	150.7	146.0

[a]10% blending sand added. [b]15% crushed gravel added. [c]5% blending sand added.
[d]Special Provision Specification permits maximum wear loss of 55%.
[e]Percent passing No. 10 sieve-48, No. 40-23, and No. 80-14.

TABLE 5

PLANT CHARACTERISTICS

Item	Plant					
	1	2	3	4	5	6
Pugmill mixer manufacturer designation	A	B	C	A	B	B
Visual estimation of pugmill condition	Good	Fair	Good	Good	Good	Fair-Good
Asphalt temperature in surge tank, F	300	305-335	305	290-300	280-285	300-310
Aggregate temperature in hot bins, F	310-320	310	290	315-330	290	315-325
Dryer fuel oil No.	5	2	5	6	5	6
Aggregate control type	Levers	Semi-automatic	Automatic	Hydraulic levers	Automatic	Automatic
Asphalt quantities measured by:	Volume	Weight	Weight	Weight	Weight	Weight
Dry aggregate mixing period, sec	None	5	8	5-8	4	3
Batch capacity, tons	-	-	-	3.0	2.5	3.5
Time for asphalt to enter pugmill, sec	17	-	-	18	14	-
Rated plant capacity, tons/hr	-	140	230	-	-	-
Approximate operating plant output, tons/hr	85	100	140	-	-	-

No attempt was made to determine the individual effects of each plant variable. There is probably much "interaction" or "countereffects," all of which are subject to change for another mix, another day of operation involving changes in weather, and with continual wear or use of the plant.

In addition to pugmill type and condition, inherent plant features which may affect aggregate coating significantly are batch size and time required for the asphalt to enter the pugmill. Controllable features, such as aggregate dry-mixing time and temperatures of materials, are also a part of the overall plant variation effect.

Test Methods

The field study was begun by scheduling preliminary work at a nearby stationary plant in order to familiarize the operators with difficulties to be encountered at a producing plant. As a result of the preliminary work, the operators became acquainted with plant operations and problems that would be encountered, thus becoming prepared for full-scale field operations of sampling and testing.

The convenient site of the stationary plant provided an opportunity to answer several procedure questions always encountered when initiating a project involving unfamiliar operations. It was decided to obtain five counts per mixing time for satisfactory "statistical strength" of the data. It was also decided to mold duplicate Marshall specimens for three samplings at each mixing time in order to obtain a satisfactory cross-section of the mix and mix variability.

Sampling and Sample Preparation.—Mix sampling was considered to be of primary importance if uniform and representative data were to be obtained. Ross Count samples were obtained in a 6-in. diameter by a 6-in. high bucket suspended from a 3-ft handle. Samples were obtained just as the batch was discharged from the pugmill mixer. This sampling method is believed to be very reliable provided the sample is taken at about the midpoint of batch discharge. The method has the disadvantage of requiring the operator to stand on the side of the truck box during loading, which is a somewhat difficult and awkward position until the operator develops a technique.

The Ross Count sample was quickly placed on the ¼-in. sieve size and hand-sieved to allow all passing ¼-in. material to pass through the sieve. It was found that immediate sieving after sampling hastened the operation, but mix characteristics and mixing time were also detected as affecting ease of sieving. The sieve was cleaned readily in a large bucket with fuel oil after each sieving operation. It was necessary to use a wire brush to clean the sieve openings. The sieve was dried completely before admitting another sample.

The R¼-in. particles were spread on paraffin-coated paper (to prevent absorption of asphalt) and allowed to cool. (Throughout this paper the term R¼-in. refers to material retained on the ¼-in. sieve.) The sample was then quartered and two opposite quarters used for the count. This procedure resulted in a total sample of about 700 particles.

Mix material for Marshall specimens was sampled by scooping a pan of mix from a loaded truck. Two specimens were molded from each pan of mix obtained. The mix sample was placed on a gas-heated hot plate to maintain temperature until compaction. The hot plate was also used for heating the compaction molds.

Ross Count Tests.—At least two operators counted any one sample. The Ross Count of approximately 700 coarse particles for each sample consisted of visually observing the coating of each particle. A particle was considered completely uncoated if only a pinpoint area was uncoated. The total number of uncoated particles multiplied by 100 and divided by the total number of coarse particles resulted in the percent uncoated particles for each sample.

Generally, counting was done in the field, but some samples were counted in the laboratory for the last three projects in order to accelerate testing. These latter counts were made as soon as possible after sampling and within a two-week interval in all cases. All samples to be counted in the laboratory were cooled in the field prior to being placed in containers in order to avoid additional coating due to particle contact.

Marshall Tests.—Compaction of Marshall specimens was a manual operation. Compacted specimens were cooled in buckets of cold water prior to being extruded with the Marshall hammer. Each specimen was placed in a small labeled box and transported to the central laboratory for testing. An effort was made to keep specimens supported on a flat surface at all times following compaction, and no specimen was placed on top of another.

Marshall specimens were retained at room temperature in the box containers for 6 to 9 days (generally 7 days) prior to testing. Specimens were tested for density, stability, flow and void content in accordance with normal Marshall test procedures.

Test Results

Ross Count test data are summarized in Table 6. Average percent uncoated particle values at various pugmill wet mixing times are shown in Figure 3. Three mixing times are shown for each mixture. Pugmill mixing times range from 20 to 45 sec but these

TABLE 6

FIELD ROSS COUNT DATA SUMMARY[a]

Mixture	Mixing Asphalt Content (%)	Pugmill Mixing Time (sec)	Pugmill Mix Temp. at Discharge (F)	Ross Count, R¼-In. Particle Size				
				Coated Particles	Uncoated Particles	Total Particles	Percent Uncoated	Percent Coated
1	5.9	20	285	689	117	806	14.5	85.5
		30	300	780	35	815	4.4	95.6
		45	300	755	6	761	0.8	99.2
2	6.2	20	300	645	95	740	12.8	87.2
		25	295	614	32	646	4.9	95.1
		35	300	678	2	680	0.3	99.7
3	6.1	20	300	607	106	713	14.9	85.1
		25	305	683	33	716	4.6	95.4
		35	300	754	7	761	1.0	99.0
4	5.7	20	310	520	76	596	13.0	87.0
		25	310	639	12	651	1.9	98.1
		35	310	640	0	640	0.0	100.0
5	5.7	25	295	568	111	679	17.2	82.8
		35	285	704	43	747	6.7	93.3
		40	285	722	8	730	1.1	98.9
		45	285	667	13	680	2.0	98.0
6	7.3	30	295	526	185	711	25.2	74.8
		35	290	652	50	702	6.7	93.3
		40	290	569	18	587	3.0	97.0

[a]Each tabulated value is an average of five test results.

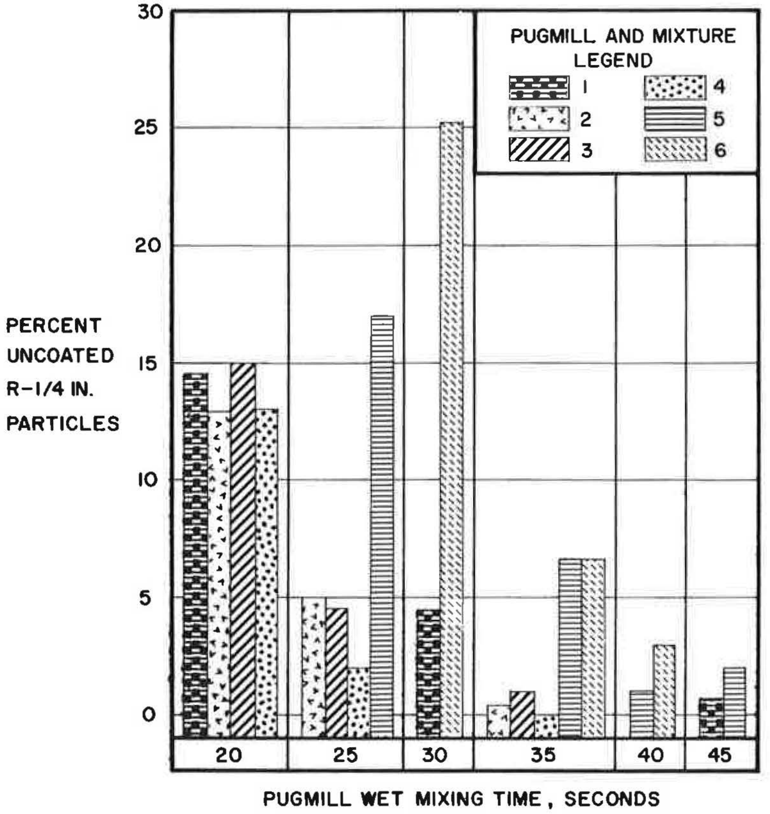

Figure 3. Percent uncoated particles at various pugmill mixing times.

TABLE 7

MARSHALL COMPACTION AND TEST DATA SUMMARY

Mixture	Mixing Asphalt Content (%)	Pugmill Mixing Time (sec)	Compactor Operator	Compaction Temp. (F)	Density (pcf)	Void Content (%)	Stability (lb)	Flow (0.01 in.)
1	5.9	20	1	260	155.2	2.8	1575	10
		30	1	270	155.3	1.3	1520	13
		45	1	270	154.9	1.9	1420	11
2	6.2	20	4	260	149.0	2.0	1010	8
		25	3	265	148.9	1.9	970	9
		35	2	260	150.2	1.6	1300	10
3	6.1	20	3	280	150.9	4.2	1540	5
		25	2	285	151.6	2.7	1490	7
		35	4	275	150.6	2.9	1355	9
4	5.7	20	2	280	151.6	2.7	1375	8
		25	4	290	152.9	1.6	1365	11
		35	2	270	152.4	2.0	1230	12
5	5.7	25	4	270	149.2	3.6	1375	9
		35	2	260	149.8	2.4	1365	10
		40	4, 2, 5	255	149.6	2.5	1335	10
		45	5	260	150.1	2.3	1395	12
6	7.3	30	5, 2	265	149.5	2.5	1615	14
		35	5	270	148.2	2.0	1490	16
		40	2	265	148.3	2.4	1050	16

[a]Specimen test age was normally 7 days but varied from 6 to 9 days. Each tabulated value is an average of six test results.

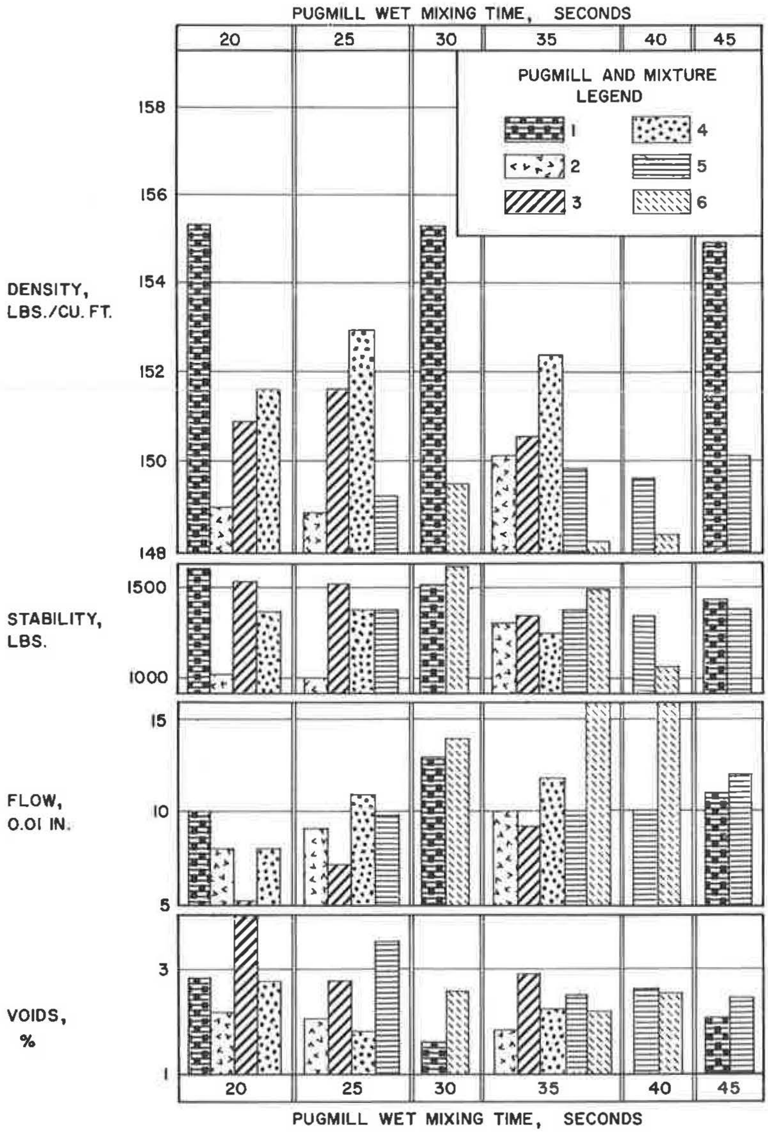

Figure 4. Marshall test properties at various pugmill mixing times.

two extremes were not used for all mixes. In several cases nearly 100 percent coating was observed at 35-sec mixing time. In other cases mixing was so incomplete at 20 sec it would have been impractical to process a count.

Table 7 summarizes the Marshall compaction and test data. Average test results at various pugmill wet mixing times are shown in Figure 4.

Analysis of Test Results

Analysis of test data generally involved working with average test values for each mixture to determine average data trends, and a statistical analysis of data variability. Considering all factors of data variability and desired aggregate coating, minimum wet mixing times were established for each of the six plants and mixes of the study. Also, a comparison of Marshall and Ross Count test results was made for laboratory mixing,

TABLE 8

AVERAGE ROSS COUNT AND MARSHALL TEST VALUE SUMMARY[a]

Mixture	Pugmill Wet Mixing Time (sec)					
	20	25	30	35	40	45
(a) Ross Count, % uncoated						
1	14.5	9.3[b]	4.4	3.1[b]	1.9[b]	0.8
2	12.8	4.9	2.5[b]	0.3	0.0[c]	0.0[c]
3	14.9	4.6	2.7[b]	1.0	0.0[c]	0.0[c]
4	13.0	1.9	0.9[b]	0.0	0.0[c]	0.0[c]
5	22.3[c]	17.2	11.8[b]	6.7	1.1	2.0
6	62.0[c]	44.0[c]	25.2	6.7	3.0	0.0[c]
Avg	23.3	13.7	7.9	3.0	1.0	0.5
(b) Density, pcf						
1	155.2	155.3[b]	155.3	155.2[b]	155.0[b]	154.9
2	149.0	148.9	149.5[b]	150.2	150.8[c]	151.5[c]
3	150.9	151.6	151.1[b]	150.6	150.1[c]	149.6[c]
4	151.6	152.9	152.7[b]	152.4	152.1[c]	151.9[c]
5	148.9[c]	149.2	149.5[b]	149.8	149.6	150.1
6	152.1[c]	150.8[c]	149.5	148.2	148.3	148.4[c]
Avg	151.3	151.5	151.3	151.1	151.0	151.1
(c) Voids, %						
1	2.8	2.0[b]	1.3	1.5[b]	1.7[b]	1.9
2	2.0	1.9	1.7[b]	1.6	1.5[c]	1.3[c]
3	4.2	2.7	2.8[b]	2.9	3.0[c]	3.1[c]
4	2.7	1.6	2.3[b]	2.0	1.7[c]	1.4[c]
5	4.2[c]	3.6	3.0[b]	2.4	2.5	2.3
6	3.5[c]	3.0[c]	2.5	2.0	2.4	2.8[c]
Avg	3.2	2.5	2.3	2.1	2.1	2.1
(d) Stability, lb						
1	1575	1550[b]	1520	1490[b]	1450[b]	1420
2	1010	970	1130[b]	1300	1460[c]	1620[c]
3	1540	1490	1420[b]	1355	1340[c]	1250[c]
4	1375	1365	1290[b]	1230	1170[c]	1100[c]
5	1360[c]	1375	1370[b]	1365	1335	1395
6	1875[c]	1740[c]	1615	1490	1050	600[c]
Avg	1455	1415	1390	1370	1300	1230
(e) Flow, 0.01 in.						
1	10	11.5[b]	13	12.4[b]	11.7[b]	11
2	8	9	9.5[b]	10	10.5[c]	11[c]
3	5	7	8[b]	9	10[c]	11[c]
4	8	11	11.5[b]	12	12.5[c]	13[c]
5	8.5[c]	9	9.5[b]	10	10	12
6	10[c]	12[c]	14	16	16	16[c]
Avg	8.3	9.9	10.9	11.6	11.8	12.3

[a]Tabulated values were obtained from average test data except where noted.
[b]Interpolated values were obtained from straight-line connections of data.
[c]Extrapolated values were obtained from straight-line extensions of data.

minimum specification mixing time of 45 sec, and the minimum mixing times established by this study.

Effect of Mixing Time.—Table 8 summarizes average test values for the three mixing periods used for each mixture. Three additional values are included which were obtained by straight-line connections or extensions of average values. The interpolated and extrapolated data are approximate but satisfactory to determine average data patterns shown by Figures 6 and 7. The trends shown can normally be expected with the indicated values being relative and only representative of data obtained.

Figure 6 shows the relationship of Ross Count variation with pugmill wet mixing time. The indicated solid-line curve is representative of 90 individual Ross Counts, supplemented with the interpolated and extrapolated data. The curve shows nearly 100 percent coating is obtained at the present minimum specification mixing time of 45 seconds. Aggregate coating will decrease progressively with reductions in pugmill mixing time.

Figure 7 shows Marshall test data trends resulting from an analysis method as described for Figure 6. Density values were relatively unaffected by mixing time

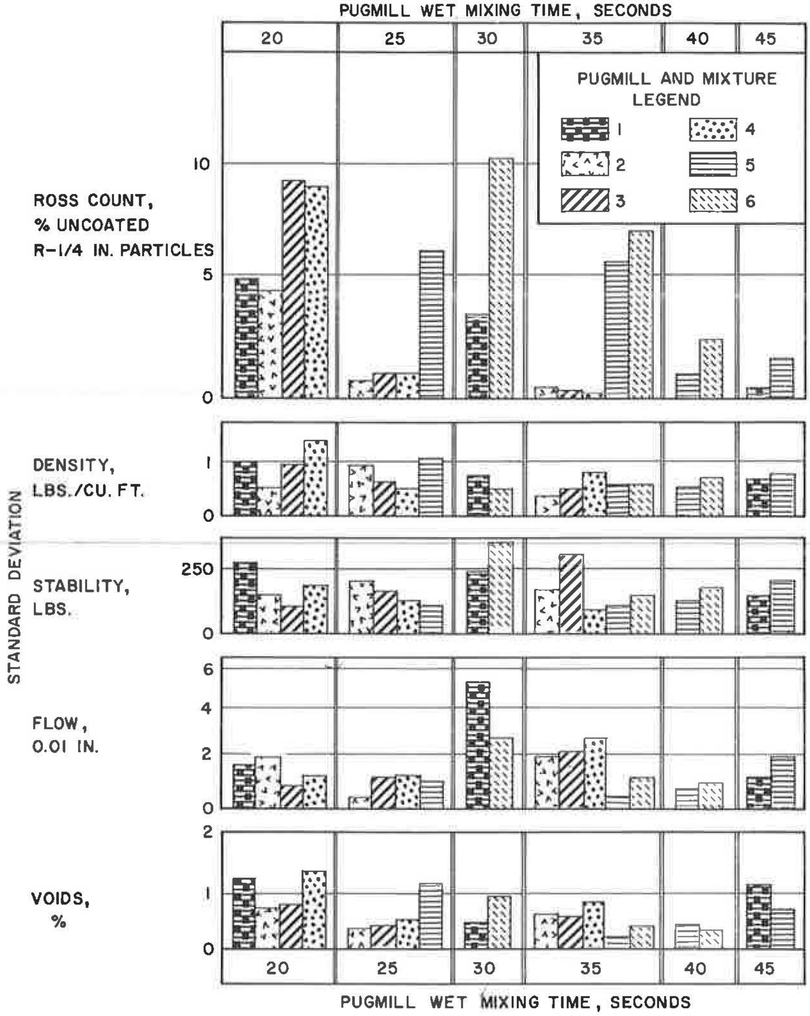

Figure 5. Standard deviation of Ross Count and Marshall test properties at various mixing times.

changes. The decrease in void contents with increased mixing time is explained as a test error. At low mixing times a mix has more uncoated particles which permits higher absorption by the aggregate during the vacuum saturation procedure of the Rice maximum density test. It is possible to correct for aggregate absorption by obtaining a saturated surface-dry weight of mix; however, this procedure is not normally followed in the mix design laboratory.

Marshall stability and flow values decreased and increased, respectively, as mixing time was increased. The variation of flow with mixing time curve in Figure 7 correlates well with the Ross Count vs mixing time curve in Figure 6. For the 20- to 45-sec mixing periods considered, the average flow range was 0.04 in. and stability range 225 lb. The void contents were at or below 2 percent for mixing times above 35 sec. The current requirements of the Wisconsin specifications lists 2 percent as a minimum. Stability became rapidly more critical above 35-sec mixing time and only slightly above the specification minimum of 1,200 lb at the 45-sec mixing period.

Variability of Test Results.—Evidence of considerable variation in test data was apparent in the analysis of results. Inspection of the data suggested that much variation was present in replicate sample test results. It was suspected, also, that changes in mixing time had affected Marshall test properties. A statistical analysis was made to determine the magnitude of test result variability at various mixing times and to determine the degree of significance of the variability.

Table 9 summarizes standard deviation values for all measured properties for each mixture of the study. As in Table 8, straight-line connections and extensions were used to complete the data. Figure 5 shows average values of standard deviation which are directly related to data represented by Figures 3 and 4.

Figure 5 indicates a standard deviation of density of less than 1 pcf in all but one case, which implies that good compaction control was obtained. Normally, the variability of Marshall properties was not affected by mixing time. Any apparent trend of

TABLE 9

STANDARD DEVIATION OF ROSS COUNT AND MARSHALL TEST VALUE SUMMARY[a]

Mixture	Pugmill Wet Mixing Time (sec)					
	20	25	30	35	40	45
	(a) Ross Count, % uncoated					
1	5.13	4.32[b]	3.58	2.51[b]	1.49[b]	0.47
2	4.57	0.75	0.58[b]	0.44	0.28[c]	0.12[c]
3	9.34	1.11	0.70[b]	0.31	0.0[c]	0.0[c]
4	8.99	1.15	0.61[b]	0.10	0.0[c]	0.0[c]
5	6.77[c]	6.42	6.13[b]	5.82	1.01	1.75
6	16.35[c]	13.28[c]	10.24	7.20	2.59	0.0[c]
Avg	8.53	4.51	3.64	2.73	0.90	0.39
$ts/\sqrt{n}$	10.58	5.60	4.52	3.39	1.12	0.48
	(b) Density, pcf					
1	0.93	0.79[b]	0.67	0.65[b]	0.64[b]	0.61
2	0.47	0.86	0.61[b]	0.36	0.12[c]	0.0[c]
3	0.91	0.56	0.50[b]	0.43	0.37[c]	0.31[c]
4	1.35	0.41	0.57[b]	0.73	0.91[c]	1.08[c]
5	1.17[c]	0.99	0.77[b]	0.56	0.47	0.68
6	1.17[c]	0.30[c]	0.47	0.58	0.64	0.70[c]
Avg	0.83	0.65	0.60	0.55	0.53	0.56
$ts/\sqrt{n}$	0.87	0.68	0.63	0.58	0.56	0.59
	(c) Voids, %					
1	1.18	0.81[b]	0.45	0.67[b]	0.87[b]	1.11
2	0.66	0.35	0.45[b]	0.57	0.67[c]	0.78[c]
3	0.75	0.40	0.45[b]	0.50	0.54[c]	0.59[c]
4	1.37	0.46	0.60[b]	0.74	0.90[c]	1.04[c]
5	1.60[c]	1.12	0.65[b]	0.19	0.41	0.66
6	2.05[c]	1.49[c]	0.92	0.37	0.29	0.19[c]
Avg	1.26	0.77	0.59	0.51	0.61	0.73
$ts/\sqrt{n}$	1.32	0.81	0.62	0.53	0.64	0.77
	(d) Stability, lb					
1	278	274[b]	270	233[b]	198[b]	163
2	159	218	203[b]	187	172[c]	157[c]
3	114	182	258[b]	333	408[c]	483[c]
4	209	137	117[b]	99	76[c]	57[c]
5	132[c]	125	120[b]	115	146	239
6	870[c]	635[c]	399	167	199	230[c]
Avg	294	262	228	189	200	222
$ts/\sqrt{n}$	309	275	239	198	210	233
	(e) Flow, 0.01 in.					
1	1.9	3.4[b]	5.4	4.1[b]	2.8[b]	1.5
2	2.1	0.4	1.2[b]	2.1	3.0[c]	3.8[c]
3	0.9	1.2	1.7[b]	2.3	2.9[c]	3.4[c]
4	1.4	1.3	2.2[b]	3.0	3.8[c]	4.7[c]
5	1.4[c]	1.1	0.7[b]	0.4	0.9	2.2
6	6.3[c]	4.6[c]	3.0	1.3	1.1	0.9[c]
Avg	2.3	2.0	2.4	2.2	2.4	2.8
$ts/\sqrt{n}$	2.4	2.0	2.5	2.3	2.5	2.9

[a]Tabulated values were obtained from computed standard deviation values except where noted. Values of n are 5 and 6 for Ross Count and Marshall test data, respectively.

[b]Interpolated values were obtained from straight-line connections of data.

[c]Extrapolated values were obtained from straight-line extensions of data.

variation can be related to the magnitude of the test values since higher test values generally show higher variation.

Generally, regarding Ross Count variability, it is evident from Figure 5 that variability was greatest at low mixing times. Thus, as the number of uncoated particles increased, the expected variability in counting increased.

Test Control Limits.—A further statistical interpretation of standard deviation data is to establish tolerance limits (confidence limits) for the various test properties. Multiplication of the standard deviation by two is one method to obtain tolerance limits (95 percent confidence limits). This procedure could have been followed for each mixture and averaged to obtain tolerance limits for data of all six mixes. However, this method would not be meaningful since it would only be applicable to the six mixes of this particular study, which may or may not be typical. Regardless, the range of tolerance limits would be high due to the wide difference in test properties for the six mixes.

To obtain reasonable tolerance limits, the relationship $\bar{x} \pm ts\sqrt{n}$ was used. The average standard deviation values in Table 9 were used for s and values of n were 5 and 6 for Ross Count and Marshall data, respectively. The resulting limits (deviations from the mean, $\bar{x}$) are shown by the dashed lines of Figures 6 and 7. To interpret correctly the tolerance lines it is necessary to consider the solid lines as representing average data for any given plant and mix. The tolerance lines, then, indicate 95 percent confidence limits for the one plant and mix having the solid-line average values, when sampling, number of replicate samples, compacting, curing and testing procedures are essentially as followed in this study.

Figure 6 indicates a tolerance range of only 1 percent uncoated particles at the 45-sec mixing time. The range increases rapidly when mixing time is decreased and reaches 21.2 percent at 20 sec. Thus, it is concluded that the reliability of a single Ross Count is decreased as mixing time is decreased. A larger number of counts would be required at low mixing times to establish an accurate Ross Count.

Figure 7 shows the following tolerance limit ranges for a given wet mixing time between 20 and 45 sec using procedures of this study and three sets of duplicate specimens per mixing time: 1.5-pcf density, 500-lb stability, 0.05-in. flow and 1.5 percent voids. It is obvious that any individual Marshall test value should be interpreted liberally. Furthermore, these data warrant increasing the number of replicate specimens in future testing programs from two to an absolute minimum of three replicate specimens per sampling.

Pugmill Mixing Time Recommendations.—Considering all previous discussions, minimum pugmill wet mixing times were established for the six plants and mixes of this study. On the basis of permitting an allowable maximum of 3 percent uncoated coarse particles for a surface mix, absolute minimum mixing times are given in Table 10. Straight-line connections of data were used to determine the mixing time intersection point for 3 percent uncoated particles. Generally, 97 percent coating would be considered adequate for mixing completeness and avoids an unreasonable specification of 100 percent coating which would not allow a tolerance for variation due to chance.

However, a contractor would incur extreme risk by operating at an absolute minimum mixing time. To add a degree of safety, it is recommended that mixing time be set to permit 1.5 percent uncoated particles on the average; which, according to Figure 6, should avoid exceeding the 3 percent uncoated limit. The mixing time increase from absolute to recommended minimum mixing time is very slight—2 to 6 sec for the six mixes of this study.

The recommended mixing times of Table 10 give unmistakable evidence that an arbitrary mixing time of 45 sec was adequate for the six mixes of this study. However, a lower mixing time would suffice in all cases. Obviously, the only way to establish a correct mixing time is to do so for each plant and mix, being aware that many variables are present and that day-to-day changes in mixing time requirements are probable because of changes in materials, weather, plant operation, pugmill condition and sampling. It is possible that certain plants, operating under set conditions to produce a given mix, would require more than 45 sec for adequate mixing as measured by the Ross Count Method.

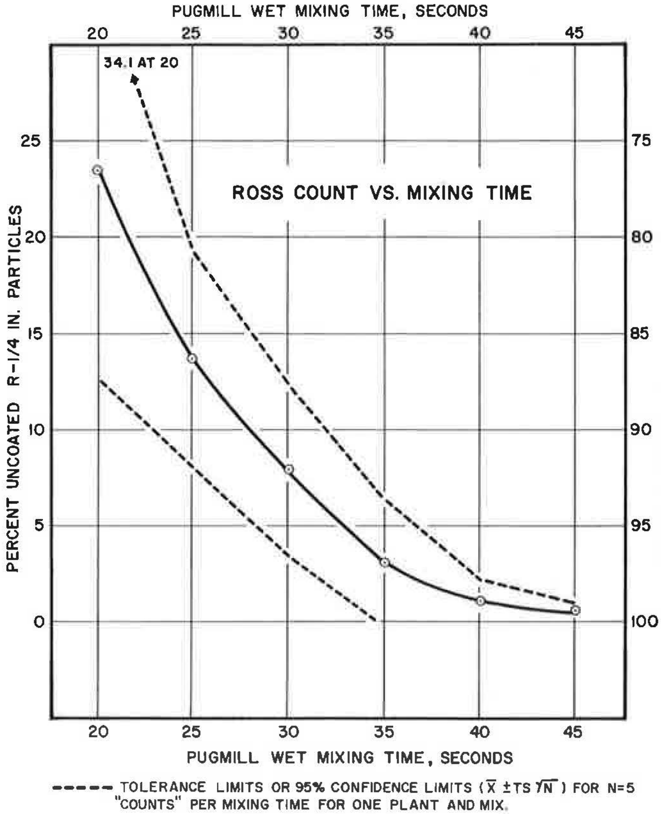

Figure 6. Variation of particle coating with pugmill mixing time (trend for average data for six plants and mixes).

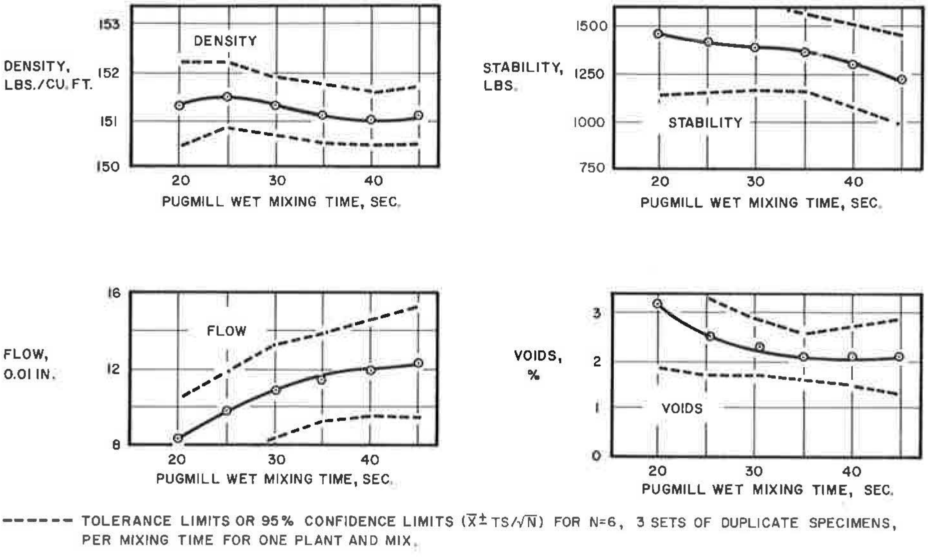

Figure 7. Variation of Marshall test properties with pugmill mixing time (trends for average data for six plants and mixes).

TABLE 10

MINIMUM PUGMILL WET MIXING TIMES SHOWN BY ROSS COUNTS

Plant and Mixture No.	Absolute Min. Mixing Time[a] (sec)	Recommended Min. Mixing Time[b] (sec)
1	36	42
2	29	33
3	29	34
4	25	27
5	38	40
6	40	43

[a]Criterion for establishing mixing time was a maximum of 3 percent uncoated $R\frac{1}{4}$-in. particles.
[b]Criterion for establishing mixing time was a mean of 1.5 percent uncoated $R\frac{1}{4}$-in. particles.

Comparison of Mix Properties at Various Mixing Times.—Table 11 summarizes mix properties of the laboratory mixes, field mixes for the current minimum specification of 45-sec mixing, and the absolute and recommended minimum mixing times of Table 10. The comparison provided by Figure 8 shows the results for laboratory mixing are different, generally, from field results at any of the three pugmill mixing times. At the recommended minimum mixing times, void contents are below the current Wisconsin specification minimum of 2 percent. However, low values are also indicated at the 45-sec pugmill mixing time. Low stability values (below the current specification minimum of 1,200 lb) are shown for two projects at the absolute minimum mix time. However, values are within the tolerance limits and are above minimum when the mixing time is increased to the recommended minimum low. The most pronounced differences between laboratory and field mix properties are for mixture 6 which consisted of a high wear loss aggregate and a high asphalt content.

TABLE 11

ROSS COUNT AND MARSHALL TEST VALUES FOR SELECTED MIXING CONDITIONS

Mixture	Marshall Test Properties				Ross Count, % Uncoated $R^1/_4$-In. Particles
	Density (pcf)	Stability (lb)	Flow (0.01 in.)	Voids (%)	
(a) Laboratory Mixing[a]					
1	155.0	1750	14	2.3	-
2	149.7	1300	10	2.7	-
3	152.4	1770	11	2.3	-
4	152.6	1570	12	2.5	-
5	147.0	1530	9	3.6	-
6	145.4	1940	9	4.3	-
(b) 45-Second Minimum Specification Mixing[b]					
1	154.9	1420	11	1.9	0.8
2	151.5*	1620*	11*	1.3*	0.0*
3	149.6*	1250*	11*	3.1*	0.0*
4	151.9*	1100*	13*	1.4*	0.0*
5	150.1	1395	12	2.3	2.0
6	149.1	1720	18	2.1	0.1
(c) Absolute Minimum Mixing by Ross Count[c]					
1	155.1*	1480*	12*	1.5*	2.9*
2	149.4*	1100*	9*	1.8*	3.0*
3	151.2*	1430*	8*	2.8*	3.0*
4	152.9	1360	11	2.6	1.9
5	149.7*	1350*	10*	2.4*	3.0*
6	148.3	1050	16	2.4	3.0
(d) Recommended Minimum Mixing by Ross Count[c]					
1	155.0*	1430*	11*	1.7*	1.4*
2	149.9*	1230*	10*	1.7*	1.2*
3	150.7*	1370*	9*	2.9*	1.3*
4	152.8*	1330*	11*	2.5*	1.5*
5	149.6	1330	10	2.5	1.1
6	148.7*	1460*	17*	2.2*	1.2*

[a]Tabulated values are from laboratory mix design reports and represent mixture properties at asphalt content used in field.
[b]Tabulated values followed by an asterisk are extrapolated from straight-line extensions of data.
[c]Tabulated values followed by an asterisk are interpolated from straight-line connections of data.

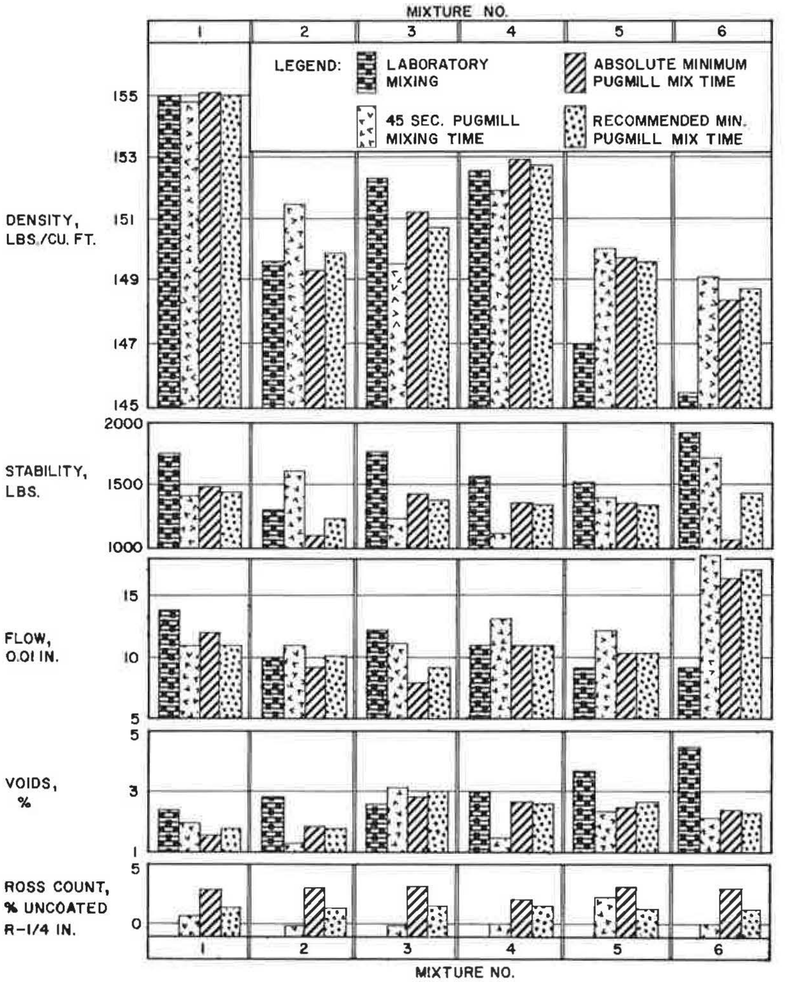

Figure 8. Ross Count and Marshall test values at various minimum mixing times.

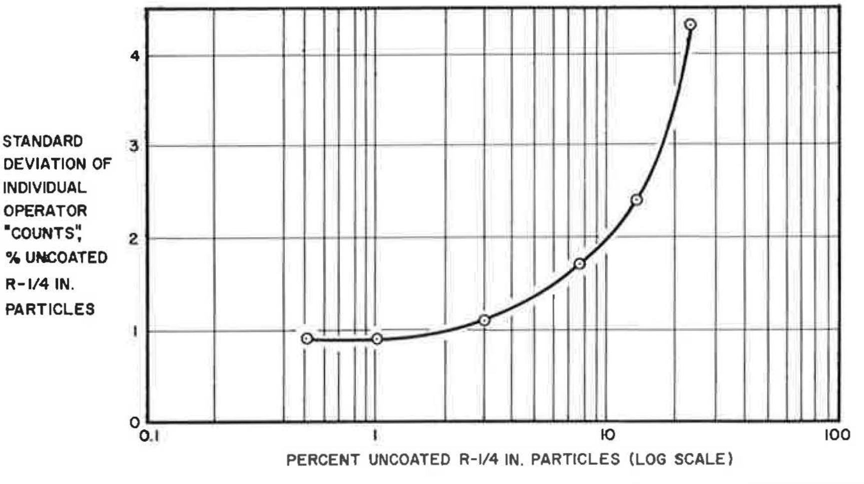

Figure 9. Effect of percent uncoated particles on standard deviation of individual operator "counts" (trend for average data for six plants and mixes).

Figure 8 also shows that the laboratory results generally correlate more closely with field test results for reduced mixing times than with 45-sec mixing time results. This phenomenon suggests that the degree of mixing in the laboratory (in addition to laboratory and field compaction differences) is different from that achieved after 45-sec pugmill mixing. The latter condition may be permitting "over-mixing," or mixing beyond an optimum period, with no apparent additional benefits gained in mix properties. Although sufficient evidence is not presented here to warrant a conclusion, it is worth considering that an optimum mixing time is possible and over-mixing may be nonbeneficial to mix quality.

Statistical Evaluation of Field Ross Count Data.—To avoid excessive delay in counting and to speed field work, two or more operators counted a sample. The statistical analysis of individual operator Ross Counts included paired comparison of counts of operators and standard deviations of counts only due to different operators counting a given split sample.

The data permitted making eight paired comparisons of Ross counts, only two of which were significantly different. It was concluded that operators counted equally and the two exceptions can be explained by one operator lacking experience, and the fact that the major differences are only related to mixture 6.

Standard deviation of counts by different operators was found to vary considerably between mixes. The standard deviation was lowest at high mixing times and increased as mixing time decreased (uncoated particles increased). The trend of standard deviation variation with mixing time on an arithmetic plot is similar to the curve shape of Figure 6. A smooth semi-log plot is obtained (Fig. 9) when the abscissa is changed from mixing time to percent uncoated coarse aggregate. Figure 9 shows an average trend from which actual values for a single project may vary excessively.

Three days were generally required to complete work at any one plant. For the final three projects it was decided to reduce the field work by field-counting only sufficient samples to establish a mixing time range, and transport the remaining samples to the laboratory for counting. Paired comparisons of 35 recounts (the recounts were made about one week after sampling) had previously shown no evidence of a significant difference due to the time at which a given sample was counted. The recount results strongly indicated that comparisons are in closer agreement when experienced counters recount a given sample than when they separate (split) and compare counts for a sample. This result is explained readily by the fact that different particles are being counted in the latter case.

EVALUATION OF ROSS COUNT METHOD

Evidence has been presented that the Ross Count Method could be used satisfactorily to establish and control minimum mixing time requirements. However, it is desirable that further studies be made to determine the effects of certain variables before incorporating the method into a field control program. At this time data are very limited and additional work is required to prove the adequacy of the method.

A Ross Count may be helpful in the case of especially troublesome mixes. In Wisconsin, a mobile bituminous testing laboratory is dispatched to a project when mix quality, as measured by Marshall properties, becomes questionable. If unwarranted mixing is occurring, a reduced mixing time, as established by a Ross Count, may possibly result in some improvement of the Marshall test properties.

Thus, the Ross Count Method could be used on an experimental basis as a part of the mobile laboratory mix control procedure. Should the method show promise as a useful field control tool for mixes, it could eventually become a part of the plant inspector's test duties. Because of the lack of data and insufficient proof of the full merit of the method, it is recommended that the test be used only on an experimental basis until more complete knowledge of the test and test variations is available.

It is advisable that plant inspectors observe coating by visual inspection of mixes. Observation of the mix in a truck is reasonably reliable, generally, for determining if the aggregate is sufficiently coated. A procedure for actual application of the Ross Count Method in establishing a mixing time could consist of observing the degree of aggregate coating and reducing mixing by 5-sec intervals until some uncoated coarse particles are observed. The mixing time should then be increased 5 sec and a Ross Count obtained to verify that satisfactory coating is being achieved.

CONCLUSIONS

The following statements appear warranted on the basis of the laboratory and field study results of this investigation, and considering information from a review of the literature and past experience.

Ross Count Method

1. The Ross Count Method offers a simple and practical means to measure the degree of coating of coarse aggregate in a bituminous mix. Decreases in mixing time are evidenced by corresponding increases in number or percent of uncoated coarse particles.
2. An individual Ross Count is less reliable at low mixing times since the variability of replicate Ross Counts increases as mixing time decreases. Thus, a greater number of counts may be required at low mixing times to establish an accurate Ross Count.
3. Experienced operators are capable of repeat counting of a given sample and, also, showing little variation when counting split samples. The counting variation is a bias, primarily, and increases as the number of uncoated particles increases.
4. The Ross Count at any mixing time is subject to numerous variables, some of which are plant and pugmill conditions, specific mixture characteristics, material changes, amount of asphalt, mixing temperature, plant operation changes, sampling, number of replicate samples counted, counting operators, and climate or humidity.
5. The Ross Count Method offers one of the most practical approaches to establishing minimum mixing times presently available. However, it is desirable that the effects and control of the numerous variables be studied before accepting the Ross Count Method as an adequate standard procedure.

Marshall Test Property Variation with Mixing Time

1. Evidence was presented to show that all six plants of the study could reduce mixing times from the current Wisconsin minimum specified mixing time of 45 sec and produce satisfactory quality mixtures as measured by the Marshall tests.
2. Reduction of pugmill mixing time to a point where 97 percent coating of coarse aggregate is obtained would not significantly affect Marshall test properties. Excessive reduction of mixing was evidenced by "balls" of asphalt in the mix, a sign of incomplete mixing or aggregate coating.
3. It was indicated that Marshall tests on field specimens showed extreme variability, and therefore, test results on an individual specimen should be interpreted liberally. Variation is caused by sampling, compacting, curing and testing procedure variations. Tolerance limits established from this study with six replicate specimens (three sets of duplicate specimens) indicate an acceptable range of 1.5-pcf density, 500-lb stability, 0.05-in. flow and 1.5 percent voids. The data suggest increasing the number of replicate specimens in future studies.
4. Figure 8 gives evidence that laboratory mixing mix properties do not compare as well with mix properties at 45-sec pugmill mixing as at the reduced mixing times of Table 10. It is suggested that "over-mixing" may result in cases when an arbitrary mixing time is used for all mixes. Sufficient evidence is not available at this time to conclude that extended mixing is not beneficial to mix quality; however, it is probable that an optimum mixing time is possible and additional mixing beyond the optimum may not significantly alter mix quality sufficiently to be warranted.

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