The Effects of Pugmill Structure and Asphalt Spraying Mechanisms on the Mixing and Properties of Mixtures

WARD K. PARR, Associate Professor of Highway Engineering, University of Michigan, and Consultant, Michigan State Highway Department

●THE MIXING process, although almost universally applied to industrial uses in one or more ways, has the least scientific foundation of any of the other common unit processes. This has been principally due to its widely diversified application to materials having extremely varied physical and chemical properties.

The mixing process, therefore, has not had developed for it a sound basis of engineering principles upon which to base design and operation making it necessary to study each individual application to obtain design data and operating characteristics.

In an asphalt pugmill it must be recognized that separate phase relationships exist during various periods of the mixing process. During the dry mixing time, there are only 2 phases present: a solid phase represented by the aggregate particles and a gaseous phase represented by the surrounding air. With the introduction of bitumen, a liquid phase appears which results in a 3-phase system during the wet mix period.

Mixing of dry materials is accomplished according to Lacy (1) by three fundamental actions: (a) conductive mixing or transfer of particles from one location in the mass to another, (b) diffusive mixing or distribution of particles over freshly developed surfaces, and (c) shear mixing or setting up of slipping or shear planes within the mass. All of these actions occur within an asphalt pugmill during both the dry and wet mix periods, but vary in importance relative to the total mixing action. It is apparent that during the drying mix period all three actions will occur quite readily and without consumption of a large amount of energy because of the free flowing properties of the dry sand, stone and filler. With the addition of bitumen (the liquid phase) there is a three-phase system which makes the process much more complex to study. Conductive mixing or transferring the particles from one location to another becomes more difficult, and diffusive mixing in the conventional pugmill will decrease to relatively little importance as far as the rate of mixing is concerned, particularly in the latter stages of the wet mix period. Shear mixing caused by the pressure of the mixing blade on the mat becomes less effective in developing fresh shear planes due to the cohesive character of the liquid-solid phase system. The presence of the liquid phase in the mixing process, however, provides for one further mixing action, that of pressure, causing the liquid to be forced around the solid particles during the wet mix period .

Certain fundamental properties affect the mixing process:

1. Consistency or apparent viscosity at mixing viscosities. Water has a viscosity of one centipoise; asphalt at the mixing temperature ranges in viscosity from 1 to $4\frac{1}{2}$ poises, which represents 100 to 450 times the viscosity of water.
2. The specific gravities of the various phases. Aggregates are generally within the same range of specific gravity values, although in some cases lightweight fillers may be used with heavier dolomitic types of aggregates providing for a differential in these properties.
3. Ease of wetting of the solid phase by the liquid phase.
4. Surface tension of the liquid phase. The surface tension of water is approximately 70 dynes while that of asphalt ranges around 25 to 30 dynes.
5. Range of particle size variation. Mixing of a range of particle sizes is more difficult than closely sized aggregate particles.
6. Variation of consistency or viscosity during the mixing.
7. Relative proportions of materials and their order of addition to the mixture.

The conventional twin-shaft pugmill has been used in the asphalt industry for years having supplanted the rotary type mixer used in the early part of the century. These pugmills originally varied from a capacity as low as 750 lb per batch, on up to 2, 000 lb, and on the basis of experience and tests by engineers in connection with their use, the mixing time and other conditions were fairly well established. Since World War II, there have appeared greatly increased capacity plants involving both continuous type pugmills and also large size batch type pugmills having capacities as high as 8, 000 lb. There is a question as to whether the criteria developed with the older small size batch pugmill are entirely applicable to the larger capacity batch and continuous units. There is a need for some fundamental research with various types of asphalt mixtures to determine functional characteristics of pugmills with respect to their effect on the mixing efficiency. Factors which need to be investigated are the following:

1. Length, width and volume relationships;
2. Shaft speed;
3. Peripheral speed of the pugmill blades;
4. Area of the pugmill blades as related to the pugmill volume or capacity;
5. Angle of the blade with the pugmill shaft;
6. Method of introducing the aggregates to the pugmill; and
7. Method of introducing the bitumen into the pugmill.

Table 1 indicates the wide variation in several of these factors on commercially available pugmills.

TABLE 1

Pugmill Size, lb	Horse Power	Radius of Paddle Tip, in.	RPM	Peripheral Speed of Tip, ft/min
2, 500	40	16⅛	65	561
4, 000	60	18¼	61	582
5, 000	75	20½	55	590
8, 000	125	25	50	655
4, 000	75	26⅜	35	484
4, 000	-	20	63	630
Continuous	-	8	70. 5	295
Continuous	-	8	52. 3	218
Continuous	-	9⅞	47. 4	246
Continuous	-	12	62	390
Continuous	-	12	47. 6	295

Presumably these are all functioning satisfactorily in producing bituminous mixes under various operating conditions.

One manufacturer has advised that both area and peripheral speed of the paddle tips are important factors in mixing efficiency. The design standards used by his company for pugmills specify a peripheral speed of 525 ft per min and a ratio of total pugmill capacity in pounds to total paddle tip area in square inches of 2. 4 to 2. 8 for a tip angle of 45 deg to shaft centerline.

The British Road Research Laboratory (2) has published a paper on tests on the efficiency on a 1-ton pugmill. The conditions under which their tests were performed are not representative entirely of American practice and the specific results obtained can only be evaluated qualitatively with respect to familiar conditions. They were particularly concerned with the rotational arrangement of the paddles or run-around as it is commonly known in this country vs. the center toss-up paddle arrangement and found that four times as long a mixing time was necessary with the standard toss-up arrangement to obtain similar uniformity in the mixtures produced in one minute by the run-around paddle arrangement. They also investigated the angle of placement of the paddle tip to the shaft centerlines, and found that, with the run-around paddle arrangement, 30- and 45-deg angles to the shaft centerline gave a more uniform distribution of the binder in the mixture in the unit mixing time than did the 15 deg paddle tip angle. The run-around arrangement is recognized in this country as the most efficient for mixing, although asphalt pugmills are still marketed with the center toss-up paddle arrangement by some manufacturers.

On continuous plants, a wide variation in paddle arrangements is available and one manufacturer, in the instruction manual accompanying this equipment, suggests four different paddle arrangements for varying types of mixes as rated by ease or difficulty in mixing. This is shown in Figure 1 for the dense graded mix containing filler and rated as difficult to mix.

The conventional method of introducing aggregates into the pugmill mixer is to weigh them in a single weigh box where the separate size fractions are deposited in layers from the individual bin. Due to the positioning of these bins over the weigh boxes there often will be a larger quantity of one size fraction at one end of the weigh box than the other. Some mixing occurs when this is discharged into the pugmill, but the mixing action must combine these various size fractions with the bitumens into a quasi-homogeneous mix during the wet and dry mixing period. Due to the ease of combining dry materials, conventional practice requires a dry mixing period in order to obtain as uniform a mixture of the dried aggregate of the various size fractions prior to introducing the bituminous binder. One manufacturer provides a separate weigh box for each size fraction of the aggregate and positions these weigh boxes so that the discharge openings lay in a line normal to the mixer shaft, thereby depositing all of the aggregates simultaneously into the center of the mixer where they are combined with each other to form a uniform aggregate mix. With continuous plants the discharge of the separately measured volumetric portions of the various size aggregates into a single bucket convey or provides for some premixing of these size fractions prior to their introduction into the pugmill itself. Because of the ease of mixing dry materials, it would be considered that not too much improvement would be possible in mixing efficiency in this dry mix phase of the mixing process outside of that which could be logically made on the basis of good engineering judgment in the design of the equipment.

In introducing the fluid bitumen into the pugmill a good deal of thought and knowledge has gone into new methods. Modern asphalt mixing plants have completely discarded the old dump type of asphalt bucket which, in addition to other disadvantages, did not provide for good distribution of the asphalt into the mixer. A modern asphalt weigh bucket on a batch plant is provided with gravity drain nozzles which distribute the

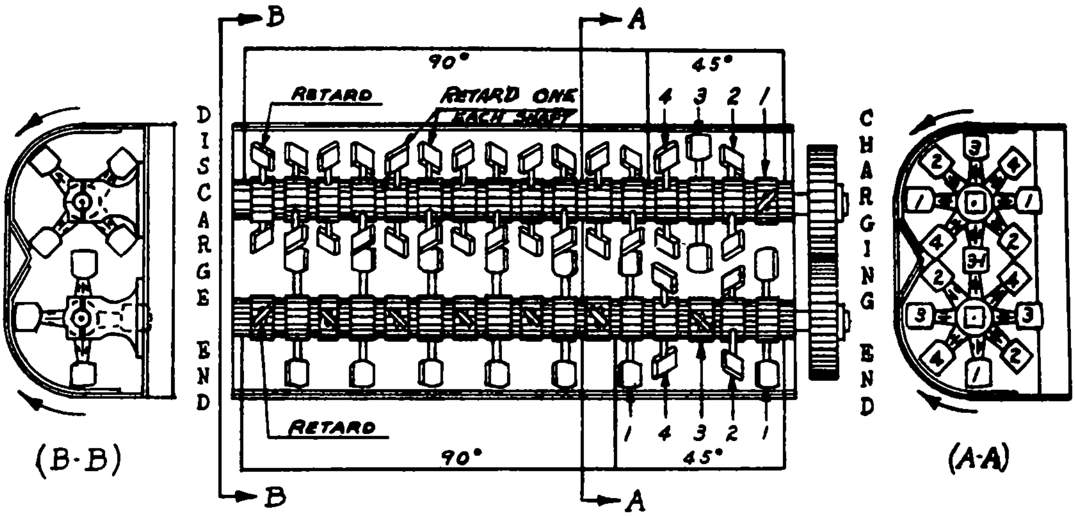

Figure 1. Paddle arrangement for continuous mixers for materials difficult to mix.

bitumen over at least 75 percent of the length of the pugmill shaft to provide for the uniform addition of this ingredient. This is usually accomplished within the first 10 sec of the wet mixing period. Some manufacturers provide for pressure spray bars and pump the asphalt from the weigh bucket or through a volumetric measuring meter to spray nozzles to distribute the asphalt in a more uniform fashion over the dry aggregate. Such an arrangement can charge the mixture in varying length of times varying from 4 to 20 sec of the wet mixing period. The continuous plant uses spray nozzles to distribute the bitumen over the aggregate at the charging end of the continuous pugmill. The more recently developed approach to the introduction of the asphalt binder is the rather recent European method by which the asphalt is atomized at high pressures to a fine mist which is impinged on the aggregate particles in the pugmill and coats them instantaneously while suspended in the air above the pugmill blades through true diffusive mixing. This involves higher operating speeds to the pugmill shaft and specially designed paddle tips to throw a curtain of the mixed aggregate up in the atomized asphalt binder. This method has only been used on an experimental basis in the United States, but in the opinion of some, offers certain advantages over the conventional method.

In the studying of asphalt mixing there might be a question as to what exactly is intended when a uniform mixture is specified. Perry's Handbook of Chemical Engineering provides an illustration of a uniform mixture and states that such mixtures are impossible to obtain in actual practice. Both theoretical and practical analysis of various mixing theories indicate that the mixing action follows a logarithmic or exponential curve approaching asymptotically to a perfect mixture. Modern sampling practice recognizes that there are variations in a single batch of a mixture and requires that for testing a composite sample made up of portions taken from different spots in the batch be combined for acceptance tests. Those conversant with statistics may be able to suggest a maximum coefficient of variations approach or some other statistical quantity as a measure of the completeness of mixing. The size of sample taken for such tests will have a definite effect on such tolerable variations. Conventional extraction and sieve analysis tests offer methods for measuring the variability of the portions of a batch although the use of tracer materials may provide for a more rapid and accurate determination than such conventional approaches. The British Road Research Laboratory supplemented the conventional extraction test by the introduction of a one size white quartzite chip into the mix in small quantities and counted the number of these chips per unit weight of sample as a method of confirming the uniformity of the mixing process. Others have used tracer elements of magnetic iron oxide, steel shot or other types of magnetic particles which could be removed from the sample magnetically and weighed to determine the uniformity of dispersment of this tracer by the mixer. The possible use of radioactive tracer elements, of course, should be considered. There is a field for investigation of the mixing process that may bear fruit through improved design of equipment, production rates and a more uniform product.

The literature provides very little data on such studies as related to asphalt mixers. There is need for concerted efforts within the asphalt paving industry to develop criteria upon which to base design of equipment, operating characteristics, and specifications for the asphalt mixing process.

REFERENCES

1. Lacey, P.M.C., "Developments in the Theory of Particle Mixing." J.Appl. Chem. 4: 257-268 (May 1954).
2. Perry, Chemical Engineering Handbook, Chap. XV, McGraw-Hill Book Company.
3. Russell, W.L., "Tests on the Efficiency of a Twin Shaft Paddle Mixer with Various Settings of the Paddle Tips." Road Note No. 21, Road Research Laboratory (1956).
4. Ward, James E. and Warden, Warren B., "Ross Count Method of Measuring Mixing Efficiency." Assoc. of Asphalt Paving Technologists, Vol. 28 (1959).
5. Tunnicliff, David G., "Laboratory Studies of the Mixing Process." Assoc. of Asphalt Paving Technologists, Vol. 28 (1959).

Discussion

H. G. Nevitt, Consulting Engineer, Kansas City, Missouri. — The mixing temperature is thought to be set by the asphalt viscosity. It is doubted that the assigned viscosity will be a uniform value, or that it will be set at the level originally recommended, despite the comparatively satisfactory results from these limits. L. C. Krchma was requested to make a study of the meager information available on the subject and derived these limits, which have proved suitable under present conditions. The reasons for anticipating a higher viscosity level are essentially that mixing equipment has become sufficiently efficient to justify higher mixing viscosities to obtain worthwhile benefits in reducing hardening and limiting absorption in some aggregates. For example, 300 Saybolt Furol viscosity is a practicable minimum working figure, and mixing can perhaps be effective at as high as 1,000 without undue difficulty although this is a point which presumably will be given more detailed investigation in the near future.

It is anticipated that high mixing temperatures will be found to be unjustified simply to obtain easy laying and rolling on distant jobs or work in cold weather. The ultimate economics of permitting undue hardening of the asphalt, or increasing the absorption simply to avoid proper handling of the mix from the plant to the job, will be found unsatisfactory. It is easy and cheap to insulate trucks properly, or even to install heating flues (as is now done in asphalt transports), if necessary to avoid losses inherent in excessively hot mixing.

The control of laying temperature will likewise probably be set by a limiting maximum viscosity.

Immediate compaction to take care of all the advantages inherent in the heat of the mixture as laid will probably become standard practice, with equipment modifications or developments, if needed, to obtain this result. That is, we look forward to quick initial compaction and to the almost complete use of efficient (pneumatic and/or vibratory) compaction equipment, with steel rollers used rather superficially and primarily for surface appearance.

Finally, we foresee the attainment of very high densities in pavements as laid. This will have two benefits. One will be to anticipate traffic compaction, the other to obtain early strength and imperviousness. From the standpoint of design, we think the ultimate density to be expected or obtainable will be a detailed design consideration. It is likely that the designer will find it worthwhile to calculate alternate conditions, with this factor varied primarily through the use of different binders, aggregate mixes, or compaction techniques. That is, the results possible from alternate materials and compaction requirements will be estimated and compared to determine the most economical program for the expected traffic conditions. To our knowledge, these factors have never been rationally evaluated. Such an evaluation must of course include other effects—such as fatigue, flexibility and durability—not now always given consideration. Quite evidently many data will be required in order to justify such an approach. But this basic concept (that is, predictability of the pavement action during its anticipated traffic life) is an important and essential step in the rational design process.

To summarize, temperature (or the properties set by it) is an important factor in asphalt pavement construction. The subject definitely needs understanding and control. It is anticipated that it will receive this in due course. Advancement in this field will be a further step in obtaining the most pavement for the least money by better engineering.

Mr. Critz.—Mr. Parr discussed quite extensively the phenomena that occur in the mixing operation. He mentioned the possibility of designing or developing an ideal mixer.

The requirements of State Highway Departments relative to the size, shape, and operation of mixers can be learned through data taken from the specifications of the 48 states, the District of Columbia, ASTM, and the Bureau of Public Roads.

Considering only the mechanical features of the mixer itself and its operation; maximum batch sizes are not stated in 37 specifications. One specifies the maximum size batch to be that which will be contained in the mixer below the centerline of the shaft. Four permit the manufacturer's rated capacity for the maximum size of the batch, and four limit the batch size, to the amount which will not extend above the tips of the paddles when stationary and in a vertical position. Three specify the maximum batch size to be set by the engineer.

Some reference is made to the minimum batch size. It used to be 750 lb. In 21 of the specifications in effect now including those that are being developed and will be published as either 1958 or 1959 specifications, the minimum batch size is not stated. One specifies a minimum of 750; three specify 1, 000; three specify 1, 500; and twenty specify a minimum of 2, 000. One is set by the engineer; one is the manufacturer's rated capacity.

With respect to the mixer itself, taking up first the number of paddles, Mr. Parr gave some data on the design of different mixers and the patterns. Thirty-four states make no mention of it, and seventeen others say "shall be adequate, sufficient and proper."

The pattern of the paddles is not states by 26 states. The runaround pattern is specifically stated by twelve, and thirteen say "shall be proper."

The speed of the paddles is not stated by forty states. Seven states require that the paddles "shall operate at a proper speed." One state requires 30 to 75 rpm; one specifies 60; and two require the speed "to be set by the engineer."

The maximum clearances are not stated in twenty specifications; twenty-four permit three-quarters of an inch; five permit an inch.

Insulation is not stated in twenty-three specifications; steam only is specified by nineteen; steam or oil by four. Those are the features that relate to the design and operation of the mixer.

In reference to the asphalt bucket and type of discharge, gravity or pressure, neither is required by eight specifications. Six require gravity discharge and in thirty-five it is optional. Seven specifications limit the time of discharge to a maximum of 15 sec; one to 17 sec.

The bucket capacity varies widely. Twenty-three states do not specify the capacity. When specified, it ranges from the amount required per batch up to two times the amount per batch, or, from 10 percent of the mixer capacity up to 30 percent. One specifies that it shall not be over 15 percent of the mixer capacity.

Mention was made of spray bars and that it was advisable to have them operate so that the asphalt was discharged into the mixer over a considerable portion of the mixer. Twenty-four specifications have no requirement; ten specify that it shall be put into the mixer over the full width of the mixer; six require discharge over the full length of the mixer; eleven specify three-quarters of the length of the mixer and two others are indefinite in their requirement.

Mr. Parr said, in his discussion on the phenomena that occur in the mixing operation, that location of the paddles and their size and speed affect the time of mixing quite considerably. This idea has apparently not received too much consideration, judging from the specified requirements.

B.A. Vallerga. —Under present construction practices on the West Coast, it is generally believed that the dry mixing cycle is not necessary and some of the reasons are as follows:

1. If the material is dropped into the weigh hopper with the larger particles first and the finer particles last, there will be adequate distribution of particles when the aggregate is dropped from the weigh hopper into the mixer.
2. Some dry mixing of the aggregate is occurring during the charging of the pugmill and during the time the asphalt is being introduced.
3. Excessive dry mixing may be detrimental to the aggregate, principally through excessive degradation, in addition to being wasteful, economically.

The differences of opinion on dry mixing seemed to be based on differences in practices between the West and the East. As a possible explanation for these differences in practice, the following are suggested:

1. Mixes in the West generally contain less material passing the No. 200 sieve.
2. The fraction passing the No. 200 sieve in the West is, more often than not, a natural material.
3. Mineral filler is seldom used in the West and often used in the East.

In addition, there is expressed opinion that the dry-mixing cycle is a carry-over from the days when asphalt was introduced at one end of the pug by a splash pan. Any segregation of aggregate caused non-uniformity of mixing as the asphalt moved across the pugmill. The advent of the spray bar across the full length of the pug is supposed to have overcome this problem and minimized the need for dry-mixing.

The general acceptance and adoption of the Sand Equivalent Test in the West, since 1954, has forced the removal of much of the very fine fraction of the natural fines passing the No. 200 sieve. As a result, there is a perceptible trend to add commercial mineral filler to high-type mixes. As yet, however, there has been no move to institute dry mixing.

The "slow setting" question was discussed earlier. A rash of "slow setting" problems began on the West Coast in 1956. These were from governmental organizations and also from commercial asphalt plants. After studying the problem, it was decided the best solution seemed to be to do one of three things:

1. Use a harder grade of asphalt initially; that is, drop to a higher viscosity asphalt;
2. Increase the dust content or add mineral filler;
3. Use rubber-tired rollers, preferably after breakdown rolling and before final rolling, although rubber-tired rolling several days after placement is beneficial in overcoming the undesirable characteristics of "slow setting" mixes.

Of course, any one of these three procedures may be used in combination.

As a result of educational efforts to eliminate the rash of "slow setting" problems, the 1958 construction season saw no complaints on slow setting.

Mr. Warden.— I suggest, to help your problem in slow setting, that lower viscosity-temperature susceptible asphalts be tried; the minimum viscosity at 275 F specification is a step in the right direction, in my opinion.

In the series of tests conducted on the research program at Barber-Green, selected samples were taken by the drop method after total mixing times of 5 sec, 10 sec, 15 sec, and up to 70 sec.

Graduations following extraction showed that aggregate distribution after 5 sec was quite uniform. There was no difference within the accuracy of the test from 10 sec to 70 sec mixing time, which meant that dry mixing for aggregate distribution is not a controlling factor, since random distribution takes place very rapidly. The primary purpose of dry mixing is to heat the cold added mineral filler and plant control is adjusted accordingly.