HIGHWAY RESEARCH BOARD

Special Report 54

Temperature in Bituminous Mixtures

1959 Conference Discussions

National Academy of Sciences—

National Research Council

publication 735

HIGHWAY RESEARCH BOARD

Officers and Members of the Executive Committee

1960

The opinions and conclusions expressed in this publication are those of the authors and not necessarily those of the Highway Research Board.

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Temperature in Bituminous Mixtures

1959 Conference Discussions

Presented at the
38th ANNUAL MEETING
January 5-9, 1959

1960
Washington, D. C.

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Preface

This report is the result of requests received from engineers to publish the presentations and discussions given at Session 9 of the 38th Annual Meeting of the Highway Research Board, held in Washington, D.C., during January 1959. The conference session on "Temperature in Bituminous Mixtures" was arranged by the Bituminous Division of the Department of Materials and Construction.

Formal papers were not scheduled for presentation at this conference. It was not anticipated that any papers or discussions would be published when offers of presentation were accepted. Permission was granted to publish the contribution by each participant after requests from others were received for publication. The material presented and the resulting discussion by all the participants were on an informal basis and should be regarded in this respect by the reader.

The conference was presented in three parts: The first concerned temperature in the materials used in the bituminous mixture; the second, the effects of temperature on the mixing of bituminous mixtures; and the third, the effect of temperature on compaction. It is obvious that it would be most difficult to separate the three parts clearly, as overlap is natural and the discussions might concern several parts or phases of the construction operation.

Due to the unavoidable absence of Bituminous Division Chairman H. L. Lehmann, who organized and arranged it, the conference was conducted by Bituminous Division Vice-Chairman A. B. Cornthwaite.

Participants

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Mark Allen, Minneapolis, Minnesota

W.H. Campen, Owner, Omaha Testing Laboratories, Omaha, Nebraska

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Mr. Collier

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Paul F. Critz, Bureau of Public Roads, Washington, D.C.

Stuart Fergus, Standard Oil Company, Cleveland, Ohio

Charles R. Foster, U.S. Army Corps of Engineers, Vicksburg, Mississippi

Frank Gardner, The Asphalt Institute, Washington, D.C.

John M. Griffith, Engineer of Research, The Asphalt Institute, Washington, D.C.

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Ward K. Parr, Associate Professor of Highway Engineering, University of Michigan; and Consultant, Michigan State Highway Department

James M. Rice, Director, Road Research Laboratory, Natural Rubber Bureau, Arlington, Va.

J.F. Tribble, Alabama State Highway Department

B.A. Vallerga, The Asphalt Institute, Berkeley, California

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Bruce Weetman, The Texas Company, Beacon, N.Y.

J. York Welborn, Chief, Bituminous and Chemical Branch, Bureau of Public Roads

Contents

Introduction

H. L. LEHMANN*, Bituminous Division Chairman, Louisiana Department of Highways

●TEMPERATURE has long been recognized as an important factor in asphalt pavement construction. For many years the mixing temperature has been controlled by specification, with the temperature of the mix during laying and rolling left to the discretion of the engineer on the project. Unfortunately, selection of these specific temperatures was for many years both empirical and arbitrary; by present standards the values assigned for a mixing limit in most cases probably were high.

The first change in this situation occurred some two decades ago using as the proper mixing control asphalt viscosity rather than temperature as such. This idea was adopted rather promptly by some agencies, has gradually been gaining wider acceptance, and is now getting general recognition. This is believed to be but a step in the badly needed evaluation of temperature effects throughout the construction process.

Temperature must be viewed from several standpoints. The first is its effect on the mix constituents. When the temperature changes, so does the viscosity, the wetting energy, and perhaps some of the properties of the aggregate which affect both the spreading and absorption of the asphalt. The second is its effect on the mixing, laying, and compaction operations as a result of these changes in the properties of the mix constituents. However, there is another factor in which temperature is involved—the rate of traffic densification. Here the temperatures are set not by the construction process but by the climatic conditions. However, some knowledge and estimation of traffic densification rates probably will be required in the ultimate rational design approach needed for maximum utilization of materials and economy in design. And last, but not least, is the effect of the temperature of the base or pavement on which the hot mix is to be laid.

The discussion topics will be followed in the order given in the program, as follows:

1. Temperature of Materials:
   - A. Effects of aggregate temperature on bituminous mix properties.
   - B. Temperature-viscosity relationship of asphalts used in the United States.
2. Effects of Temperature on Mixing:
   - A. Effects of asphalt cement viscosity at mixing temperature on properties of bituminous mixtures.
   - B. Effects of mixing temperature and time on consistency of asphalt cement during mixing.
   - C. Effects of pugmill structure and asphalt spraying mechanism on mixing and properties of the mixtures.
3. Effects of Temperature on Compaction:
   - A. Temperature of mix.
   - B. Temperature of air and base.

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* Read by A. B. Cornthwaite.

Effects of Aggregate Temperature on Properties of Bituminous Mixtures

JAMES M. RICE, Director, Road Research Laboratory, Natural Rubber Bureau, Arlington, Virginia

●THIS SUBJECT might be disposed of simply by stating that the temperature of the aggregate controls the temperature of the mixture. Actually, on a pound-for-pound basis the asphalt at 300F will have a somewhat greater heat content than the aggregate. The specific heat of asphalt is about 0.5, and for aggregates about 0.2—that is, 0.2 calories per gram per degree Centigrade or Btu per pound per degree Fahrenheit. However, the mass of the aggregate will be from 10 to 25 times that of the asphalt, so the aggregate temperature will control the temperature of the mix.

For hot mixtures, the critical temperatures are those required for mixing and for compaction. The proper temperatures and effects of improper temperatures will be discussed by others at this conference.

One aspect that should be mentioned, however, is the effect of mixing temperature on asphalt absorption. For absorptive aggregates, the higher the temperature, the greater will be the amount of asphalt absorbed by the aggregate. This is due to the decrease in viscosity of the asphalt with increase in temperature. Due to variations in asphalt absorbed, a too high temperature may result in a mix with a lean appearance, whereas a too low temperature may give an overly rich appearance. Also, in cold weather is it usually necessary to raise the mixing temperature in order to maintain the proper compaction temperature. To offset the increased absorption, it may be desirable to increase the asphalt content. Thus, there can be interaction between temperature and required asphalt content.

Wet Aggregates

All aggregates, whether absorptive or not, will contain some moisture while stockpiled, depending on humidity, wind, and time since the last rain. The moisture content is important, as the heat required to raise water from ambient temperatures to 300F is 25 to 30 times as great as that required to raise the temperature of the aggregate the same amount. Variations in moisture content during production may result in variable aggregate temperatures.

The foregoing values are based on the assumption that the moisture is present as free water. Thelen[1] has discussed the adsorbed layers of water on quartz. He stated that to remove all of the water from quartz requires temperatures above 1000C; that is above 1800F. Temperatures in the vicinity of the flame may be higher than 1800F and may remove all of the adsorbed surface water. This could account for certain discrepancies that have been observed in the study of the water resistance of aggregates. One case is recalled where an oven-dried laboratory sample of quartzite showed a poor resistance to water, but a sample taken from the plant drier, kept dry and hot, showed much better stripping resistance.

Heating of the aggregate may have other incidental effects, such as calcination of the surfaces of limestone aggregates, the induration of dust coatings on wet aggregates, the baking of clay balls, and the deposition of soot on the aggregate.

Absorptive Aggregates

Aggregates which absorb and retain relatively large amounts of water have given trouble in hot mixes. The phenomenon is not too clearly understood, but the effects are quite evident, as follows:

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[1] Thelen, E., "Surface Energy and Adhesion Properties in Asphalt-Aggregate Systems." HRB Bull. 192, p. 63 (1958).

1. The mix slumps in the truck and appears rich and slick.
2. There may be foaming and flushing of the asphalt.
3. Water drains from the mix in the truck and in the paver.
4. Aggregate particles are stripped of asphalt.
5. Shoving occurs under the roller due to reduced adhesion and cohesion.
6. Segregation of the mix occurs, causing roughness and "fat" spots.

The phenomenon may possibly be explained as follows: A wet and absorptive aggregate particle, in passing through the drier, is first heated at the surface. The heat conductivity of aggregate is very low and during the two or three minutes that the aggregate is in the drier, the heat does not penetrate to the interior of the particle. Penetration of the heat continues in the hot elevator, screens, and bins. Eventually the moisture within the pore spaces of the particle is vaporized. This vaporization may force moisture farther into the particle, and steam will be evolved into the mass of the aggregate. This steam remains with the aggregate until it comes into contact with some colder medium. The hot mix is dumped in the truck and covered with a tarp. Moisture condenses on the sides of the truck and under the tarp; the steam within the mix migrates toward the cold surface and in so doing causes stripping of the aggregate, foaming, and flushing of the asphalt.

Another important aspect is that after leaving the drier the over-all temperature of the aggregate decreases, due to heat consumed in vaporizing pore water and other heat losses. As the temperature decreases, water condenses from the saturated vapor and may be adsorbed on the surface of aggregate particles. This moisture layer may retard or prevent thorough coating and adhesion of the asphalt.

There are several possible remedies to overcome these effects. The first is to apply more heat; however, this may not be effective in all cases. More rapid heating will create a steeper temperature gradient, which might actually accentuate the ill effects. A second alternative is to increase the drying time. This is very effective, but will reduce production unless tandem driers are used. A third solution, reported by Heacock,[2] is to use less heat. He cited a case where foaming of the asphalt was observed in the truck with a mix temperature of 285F, but when the temperature was reduced to 265F the foaming disappeared. Apparently, reducing the heat overcame the difficulty by leaving more moisture within the aggregate pores. A fourth solution is to increase the ventilation wherever possible.

To insure against trouble from water, specifications may require a maximum moisture content of the heated aggregate. Michigan uses a limiting value of 0.05 percent; the Corps of Engineers specifies 0.15 percent for aggregates with absorptions of 2.5 percent or less, and 0.25 percent for absorptions greater than 2.5 percent. Such restrictions have been criticized by Nevitt,[3] who believes that it is extremely uneconomical to require very low moisture levels, and that the best solution is to merely heat the aggregate sufficiently to dry surfaces and to give good mixing.

There is no question that the temperature of the aggregate is an important factor in bituminous mixtures. However, it would appear that further research is needed to develop more information on the effects of moisture and the moisture levels that are permissible with different types of aggregates.

Discussion

W.H. CAMPEN, Owner, Omaha Testing Laboratories, Omaha, Nebraska — In discussing the effects of aggregate absorption during the mixing of bituminous paving mixtures, Mr. Rice suggested that low temperatures be used in order to minimize the absorption of asphaltic cement. This suggestion is a dangerous one. Experience has shown that absorptive aggregates continue to absorb asphalt after the mixtures have been prepared and laid. The process has the effect of drying up and embrittling the

[2] Heacock, R., "Discussion of Plant Control of Bituminous Concrete." Proc. Assn. of Asphalt Paving Technologists, 23:330 (1954).

[3] Nevitt, H.G., "Drying." Roads and Streets, 101:1, 115 (Jan. 1958).

mixtures, with consequent cracking and raveling. Instead of minimizing asphalt absorption during mixing, therefore, it would be better to thoroughly dry the aggregate before adding the asphalt and thereby accomplish most of the absorption during the mixing and laying operations.

It should be pointed out that highly absorptive aggregates are inherently dangerous. It is difficult to thoroughly dry them by normal dryers. It is difficult, also, to predict the ultimate asphalt absorption. Unless there is no alternative, aggregates having a water absorption of more than 2 percent should not be used.

Temperature-Viscosity Relation of Asphalts Used in the United States

J. YORK WELBORN, Chief, Bituminous and Chemical Branch, Bureau of Public Roads

●THIS REPORT presents information on the viscosity of asphalt cements produced in the United States for use in highway construction. The viscosity data used here are part of a comprehensive study of the properties of asphalt initiated by the Bureau's Division of Physical Research in 1954. It was undertaken to provide information on a national scope to show the properties of asphalts produced from various crude sources and by methods of refining in current use.

Through the cooperation of the regional offices of the Bureau of Public Roads and the states within each region, 323 samples of asphalt cement representing 105 refineries were obtained. Asphalt cements of a number of penetration grades were included. However, the best coverage of all the refineries was in the 85 to 100 penetration grade. A total of 146 asphalts of the 85 to 100 grade were received, including a number of duplicate samples submitted by different states within a region. After eliminating these duplications 119 samples were used for an evaluation of the properties of the asphalts.

The asphalts collected for this study were tested to determine those characteristics in general use as specification requirements and those that are being used by some agencies to provide more information on the asphalts or to obtain better materials.

Some state specifications have requirements for Furol viscosity at 275 F. Other states also require that the temperatures used for plant mixing of asphaltic mixtures and for application by spraying be based on the viscosity of the asphalt. Thus, to determine the range in viscosity of present day asphalts, Furol viscosity tests were made on the asphalts of this study. Although determinations are being made over a wide range of temperature, only Furol viscosity at 275 F of the 85 to 100 penetration asphalts are presented in this discussion. Because of the large number of samples tested the viscosity data are given by a grouped frequency distribution chart in the form of a frequency polygon. The results of each viscosity result on the 119 samples of asphalt were grouped into cells or intervals and the total number of values in each cell were then plotted and their mid-points connected to form the polygon. The frequency distribution for Furol viscosity at 275 F is shown in Figure 1.

The Furol viscosity of the 119 asphalts ranges from 85 to 318 seconds. Four asphalts have viscosity values less than 100 seconds; two asphalts, more than 300 seconds. The viscosity of 80 asphalts is within the range of 150 to 250 seconds.

It is evident from the results of this survey on properties of asphalts used in the United States that the viscosity varies greatly and that this property should be recognized in plant mixing of asphaltic mixtures, spreading and compacting of the mixtures on the road, and application of asphalts by spraying. It is believed that a thorough study of the effect of viscosity on these operations should be initiated, as it could ultimately lead to higher quality and more durable bituminous surfaces.

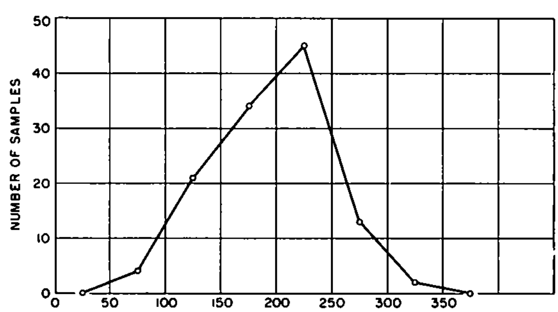


Figure 1. Distribution of Furol viscosity results.

Discussion

Mark Allen, Minneapolis, Minnesota.— Was the penetration range corrected?

Mr. Welborn.— These were all 85 to 100 penetration grade asphalts. Asphalt cements of penetration grades other than 85 to 100 would have different viscosities. A large number of asphalt cements of different grades are on hand and it is planned to test and report on them at a later date. Complete data will show the relation of viscosity to penetration.

Stuart Fergus, Ohio.— What viscosity, or range of viscosity, is best?

Mr. Welborn.— Others on the panel, specifically Messrs. Griffith and Halstead, plan to discuss that point later on. I would like to reserve the answer for them.

Clark Mitchell, Allied Chemicals.— There has been considerable difficulty with asphalt, particularly in a couple of my company's Midwestern plants, where the material refuses to set up in any reasonable length of time; that is, within a period of weeks. Is there any tie-up between this and the low viscosity encountered in the spray—somewhere in the range of 160?

Mr. Welborn. — I know of one instance where the asphalt mixture was "tender," or did not "set-up," that was attributed to the use of a low viscosity asphalt cement. It seems reasonable that this could be the contributing factor, especially during hot weather. It also is possible that aggregate gradation and small amounts of moisture retained in the aggregate after drying would have similar effects.

Effects of Asphalt Cement Viscosity at Mixing Temperature on Properties of Bituminous Mixtures

JOHN M. GRIFFITH, Engineer of Research, The Asphalt Institute, Washington, D.C.

ASPHALT is a versatile family of materials, not a single product. Included in the group are asphalt cement, rapid and medium curing cutback, emulsified asphalt, and slow curing liquid asphalt—each type available in several grades. These many types and grades of asphalt are used for a wide variety of construction applications. One common feature in all of these applications, however, is that the product must be brought to proper fluidity for the particular application under consideration.

Asphalt is a thermoplastic material which is made fluid by heating. It may also be made fluid by emulsification with water or by blending with petroleum solvents. In many applications, proper fluidity is achieved by a combination of these processes. Regardless of how this fluidity is achieved, however, it is a well established fact that proper fluidity is essential for the successful use of all of these materials.

Fluidity is a factor that is well understood by the physicist and the hydraulic engineer, although they normally think of this factor in terms of viscosity, the inverse of fluidity. Viscosity is a fundamental property of all liquids and may be measured in absolute units (poises) or in kinematic units (stokes). However, in the field of asphalt technology it is common practice to measure viscosity by the Saybolt Furol viscosity test. In this test, the time in seconds required for 60 ml of asphalt at a given temperature to flow through a Furol orifice of given dimensions is determined. Viscosity at this temperature is then expressed in terms of seconds, Saybolt Furol. Capillary-tube viscometers are now coming into wider use in asphalt refineries, as they offer certain advantages over the Saybolt Furol method. Regardless of how the viscosity may be measured, the fact remains that it is a fundamental property of asphalt in a fluid state. A better understanding of this fundamental property, and its appropriate use by asphalt paving engineers, will undoubtedly lead to better and more uniform asphalt pavement construction.

One popular misconception about asphalts is that the viscosity characteristics of a given type and grade are constant, regardless of the source of the asphalt. Evidence of this misconception may be found in many specifications, which require, for example, that all mixes prepared with an 85-100 penetration grade of asphalt cement be mixed within a certain temperature range. This may result in improper mixing, non-uniform mixtures, and faulty construction.

To illustrate this point, data have been taken from a report by a reputable agency operating in a specific locality of the United States. These data were not specially selected for purposes of this discussion, but represent all of the data contained in this report for 85-100 penetration grades that had been used by the agency. Temperature-viscosity data for these 85-100 penetration grade asphalts are shown in Figure 1. As will be noted, 77 F the penetration of asphalt A is 86, of asphalt B is 95, and of asphalt C is 93.

Let it be assumed that an agency requires mixes with an 85-100 penetration asphalt to be prepared within the range of 275 to 325 F. With such a specification, it is common practice to use the middle of the range, which in this case is 300 F. Figure 1 indicates that at 300 F asphalt A would have a viscosity, in terms of seconds, Saybolt Furol, of 150, the viscosity of asphalt B would be 107, and of asphalt C would be 57. Thus, the viscosity at 300 F of asphalt C would be less than one-half that of asphalt A.

Looking at these data from another viewpoint, assume for a moment that the ideal degree of fluidity for preparing an asphalt paving mix with an aggregate of given type and gradation is 100 seconds, Saybolt Furol. It may be seen that such a mix should be prepared with asphalt A at a temperature of 315 F, asphalt B at 302 F, and asphalt C at 280 F. The difference in temperature for equal viscosity of asphalts A and C is

VISCOSITY VS. TEMPERATURE FOR ASPHALTS

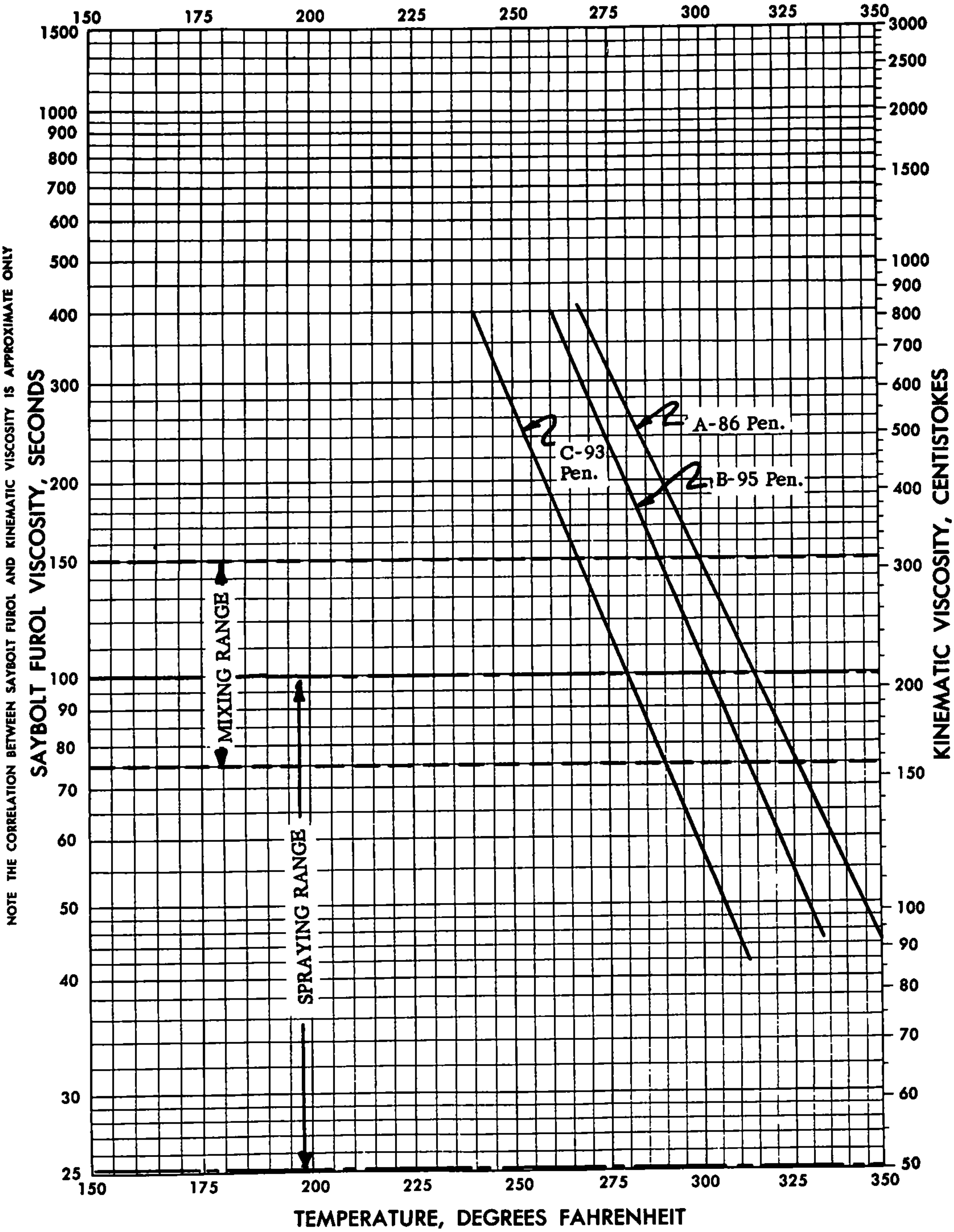
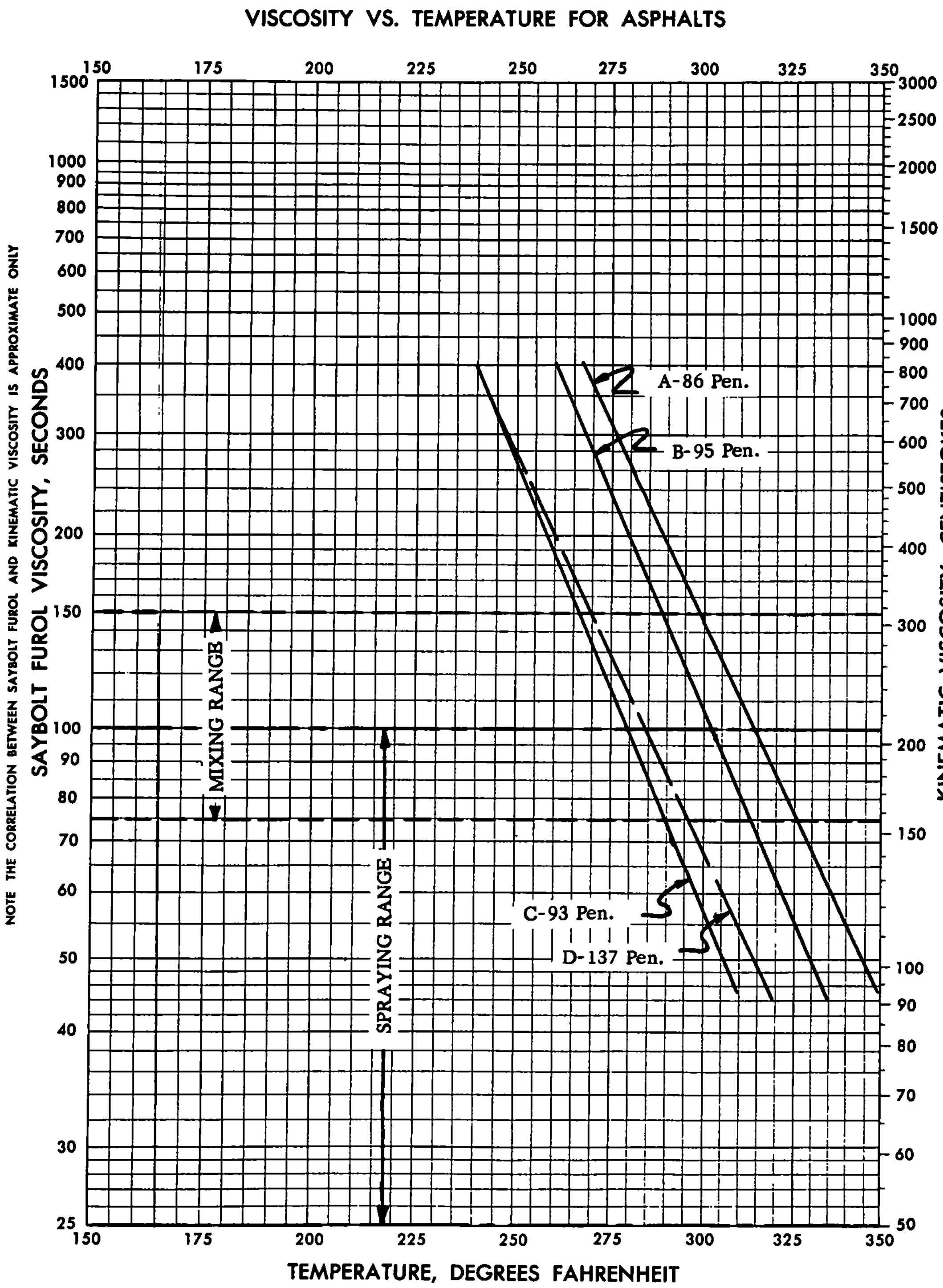


Figure 1



VISCOSITY VS. TEMPERATURE FOR ASPHALTS
SAYBOLT FUROL VISCOSITY, SECONDS
KINEMATIC VISCOSITY, CENTISTOKES
TEMPERATURE, DEGREES FAHRENHEIT
NOTE THE CORRELATION BETWEEN SAYBOLT FUROL AND KINEMATIC VISCOSITY IS APPROXIMATE ONLY
MIXING RANGE
SPRAYING RANGE
A-86 Pen.
B-95 Pen.
C-93 Pen.
D-137 Pen.
150
175
200
225
250
275
300
325
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Figure 2.

35 F, which is indeed a substantial temperature difference.

Figure 2 illustrates one further point relating to this discussion. The three solid lines are the same data as shown on Figure 1. But, in addition, the dashed line represents temperature-viscosity data for an asphalt of 137 penetration. The temperature-viscosity characteristics of this 137 penetration asphalt are almost identical with those of asphalt C which has a penetration of 93. This difference in penetration is 44 points and, in terms of penetration measurements, is significant.

The purpose of the discussion so far has been to bring out the substantial differences in temperature-viscosity characteristics of asphalts which may be encountered. These differences are to be expected as asphalts today are refined from a wide variety of crude petroleum sources. However, these differences should not be disturbing to the informed paving engineer who recognizes them and adjusts his construction procedures accordingly.

It seems obvious that an understanding of these temperature-viscosity variations and proper utilization of this knowledge cannot help but result in more uniform and better asphalt construction. Using extreme examples for purposes of illustration, one certainly would not attempt to mix an 85-100 penetration grade of asphalt cement with an aggregate when both were at ambient temperatures. Thorough and uniform coating of the aggregate particles could not possibly be achieved under such conditions and, even if this were achieved, the mix could not be properly compacted as a pavement. At the other extreme, too high a degree of fluidity might well result in some of the asphalt draining off of the surface of the aggregate in transit, collecting in pools and causing fat and lean spots in the pavement. In addition, the excessive heat required to achieve this fluidity would be unduly harmful to the asphalt deposited in relatively thin films on the aggregate particles.

It is only logical, therefore, that for a given type and gradation of aggregate there is a corresponding "optimum" viscosity for mixing. This optimum viscosity is one at which all aggregate particles may be readily and uniformly coated with asphalt in a relatively short period of time, at which the asphalt is sufficiently viscous to remain in place on the aggregate particles and at a temperature which will have a minimum hardening effect on the asphalt cement. This viscosity may vary to some extent with variations in type and gradation of aggregate. The Asphalt Institute presently recommends that a mixing temperature be selected which will result in an asphalt viscosity of 75-100 seconds, Saybolt Furol. Later, as additional experience is gained with the viscosity approach, there may be a need for some adjustment of these limits. But, it is believed that they are sufficiently accurate to result in substantial improvements in asphalt pavement construction if used in place of current practice wherein a temperature range is specified without regard to the viscosity characteristics of the asphalt in this temperature range.

Likewise, there is no doubt that better spraying applications could be achieved by giving proper consideration to the temperature-viscosity characteristics of the particular type and grade of asphalt being used. For spraying, The Asphalt Institute recommends a viscosity of 25-100 seconds, Saybolt Furol.

In conclusion, it is emphasized that viscosity is a fundamental property of asphaltic materials which should be given thorough consideration in all of its construction applications. A proper understanding of this fundamental property, knowledge of how it varies with different asphalts, and appropriate use of this knowledge will unquestionably lead to more uniform and higher quality asphalt construction.

Discussion

Charles R. Foster, U.S. Army Corps of Engineers, Vicksburg, Mississippi. — I would like to ask him to emphasize the desirability of not getting the asphalt hot. I do not think there is any minimum point—any heating damages the asphalt, and the heat damage must be kept as low as possible.

From experiences with tar mixes, we have mixed at viscosities almost off your chart. I think your 150 is much too low a limit. We have not tried any asphalt at that, but I think you should try asphalt at a lower temperature. We can run the aggregate at 225 and not damage the asphalt.

Mr. Griffith. — It was my intent to point out that the control of mixing temperature on a viscosity basis will result in better and more uniform asphalt mixtures than the use of temperature control alone, as now commonly practiced.

The recommended viscosity range of 75-150 seconds was proposed some 10 or 15 years ago, and there still seems to be a general agreement that this is an appropriate viscosity range for mixing.

I would not disagree with the point raised by Mr. Foster as to the desirability of mixing at the lowest possible temperature; provided that aggregate drying efficiency and mixing efficiency are not impaired. Whether the 150 second viscosity limit can be exceeded to any appreciable extent without adversely affecting these factors is a matter which needs further study.

Perhaps some adjustments in the recommended viscosity limits may be justified on the basis of further studies and experience with this approach. If so, these adjustments should be made. Until further evidence is available, however, we believe that the 75-150 second range is appropriate and are convinced that the control of mixing temperatures on a viscosity basis will result in better and more uniform asphalt mixes.

W. Miles Warden, Miller-Warden Associates. — I agree with the others that 150 limit is questionable.

In a recent discussion with Harry Nevitt, he said he knew someone would ask why he picked the 75 to 150 range in 1943. Since then, they have mixed at a viscosity of 300 with no trouble at all, and as high as 1, 000 with little difficulty in compaction, depending on the mix.

I think a great deal of this depends on the mix design, the amount of filler, the temperature, and the compaction range. The small range of 75 to 150 imposes an undue hardship on the contractor. That gives him the extreme range, ± 10 F on your chart.

We feel that he can more safely stay below the dangerous upper limit of 75 seconds by lowering the limit of 150 seconds very safely, and in a very practical manner.

Mr. Griffith. — I would agree that the proper mixing viscosity depends to some extent upon the characteristics of the aggregates in the mixture. In plant-mix macadam, for example, thick films of asphalt are desirable and higher viscosities may be needed to achieve this result. Generally speaking, however, most asphalt paving mixes are of the dense-graded type where relatively thin films of asphalt are required. For such mixes, perhaps it can be established that the 150-second limit may be increased. This remains to be determined on the basis of further experience with this approach.

The 75-150 second mixing viscosity range is not necessarily a final and unalterable recommendation on our part. We will maintain an open mind on this question and make such adjustments as may be properly established.

As to the recommended temperature tolerance of ± 10 F, it is my belief that this requirement is not unduly restrictive. Perhaps a little more rigid control of mixing temperature will do much to alleviate some problems presently encountered in asphalt construction.

C.W. Chaffin, Texas Highway Department. — There are no data on actual measurements of drops in penetration. Have you considered that overheating 15 or 20 degrees may injure some asphalts more than it will others, even though they are at the same viscosity and that you might approach this from a standpoint of drop in penetration?

Mr. Griffith. — No. The approach is primarily from the standpoint of mixing efficiency. The lower limit of viscosity should be such as to minimize hardening of the asphalt from overheating. If it is established that 75 seconds viscosity is too low and that it can be raised without impairing mixing efficiency, this should be done.

Such adjustments should be made on the basis of further study and experience with the viscosity approach. Out principal interest at this time is to encourage the viscosity approach for the control of mixing temperatures. It is felt that this approach, with properly established limits on viscosity, will help eliminate undue hardening of asphalts during mixing.

The recommended range of 75-150 seconds is a starting point. This range has been discussed for many years and there seems to be a general agreement that it is of the proper order of magnitude.

When initiating new recommendations of this nature, one does not expect unanimous agreement on all of the details. But, if the highway departments will adopt the viscosity approach and actually use it as a measure of field control, I feel sure that we will be able to verify or modify the recommended range of 75-150 seconds, as required, to minimize hardening of the asphalt and, at the same time, insure proper mixing.

Felix C. Gzemski, Atlantic Refining Company, Philadelphia, Pa. — As far as the BPR test is carried arbitrarily at 325, it unduly punishes one asphalt as compared to another. In other words, if the BPR test were carried out at viscosity temperatures rather than a 325 temperature, you would have a definite relationship and a penetration loss. Asphalt will be at a much lower viscosity, and will harden slower at 325. So there is a correlation between penetration loss and even temperature.

Effects of Time and Temperature on Hardening of Asphalts

F.N. HVEEM, Materials and Research Engineer, California Division of Highways

●EVER SINCE asphalts have been used for any engineering purpose it has been recognized that in order to apply the material as a surface coating or as a cementing agent in paving mixtures the material must be liquefied by some means. One means of accomplishing this is through the dilution with a more or less volatile solvent to form the so-called cutbacks. A more recent technique is through emulsification. By far the oldest method and the one still most widely used is to liquefy the asphalt by elevated temperatures. However, heating of the asphalt alone is ordinarily not sufficient for manufacturing paving mixtures. The asphalt content is usually less than 10 percent of the total and the specific heat of the asphalt is low; therefore, it becomes necessary to heat the aggregates as well as the asphalt, and so far as paving mixtures are concerned it is the temperature of the aggregate that is of most concern to the engineer.

It is not particularly difficult to heat the aggregates sufficiently to permit thorough mixing or coating with the asphalt, but unfortunately all asphalts harden very rapidly when brought into contact with a surface of solid materials heated to high temperatures. Therefore, one of the principal requisites for getting the best results from asphalt pavements is the control of plant temperatures. The aggregates must be hot enough to permit mixing and spreading and compacting on the street after the haul from the plant, but they should never be hotter than necessary to accomplish these purposes. It is also true that paving asphalts vary considerably in their susceptibility to being hardened.

Figure 1 illustrates the drop in penetration that occurred with two different asphalts. The dashed line represents a 50 penetration California asphalt showing the drop in penetration that resulted from different temperatures in the field mixing process. The solid line was taken from a report by J.G. Schaub and W.K. Parr presented at the Montana Bituminous Conference in September, 1939. Here an 85 penetration asphalt shows a relatively linear relationship, the penetration of the recovered asphalt varying inversely with the mixture temperature. The difference in penetration between these two asphalts after mixing at 350 F illustrates the reason why certain states began to use softer grades of paving asphalt some 20 years ago. Although all grades and all types of asphalt appear to harden under these conditions, the softer grades begin their service life at a higher penetration than where an initially harder grade is used.

Figure 2 is a curve taken from the paper by Schaub and Parr showing the effects of mixing time on the penetration of the recovered asphalt. While a smooth curve is drawn between the points, the penetration after 30 seconds is nearly as low as was found after 150 seconds. This same trend is illustrated by Figure 3 which represents two different California asphalts, one having an initial penetration of 170 and the other an 85 pen. In this case, the penetration was little if any different after 5 min of mixing compared to the hardening that occurred in 1 min. These curves and other observations generally support the opinion that the hardening of asphalt occurs very rapidly as soon as the material is brought into contact with the heated surfaces of the stone particles. This may be due to some rapid evaporation of volatiles but it seems more likely that it is also an oxidation phenomenon.

Most studies of asphalt hardening (like the data shown on the first three charts) involve the recovering of the asphalt from the paving mixture and then making penetration tests. However, there is considerable question whether a drop in penetration necessarily implies a corresponding loss in quality; therefore, California has developed an abrasion type of test which is intended to evaluate brittleness. It can be shown that two asphalts of the same penetration may vary considerably in brittleness as represented by the loss under an abrasion type of test. Figure 4 shows abrasion loss in grams of Ottawa sand mixtures prepared in a controlled laboratory mixer at two different temperatures. These curves show clearly a much greater brittlemess and susceptibility

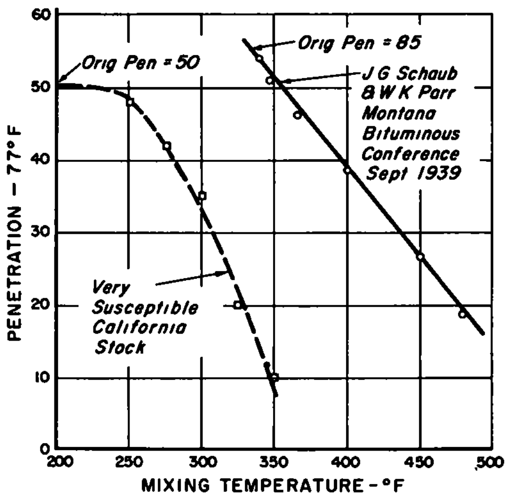

Figure 1. Relation of mixing temperature of bituminous concrete to penetration of recovered asphalt (curves from field mixer studies).

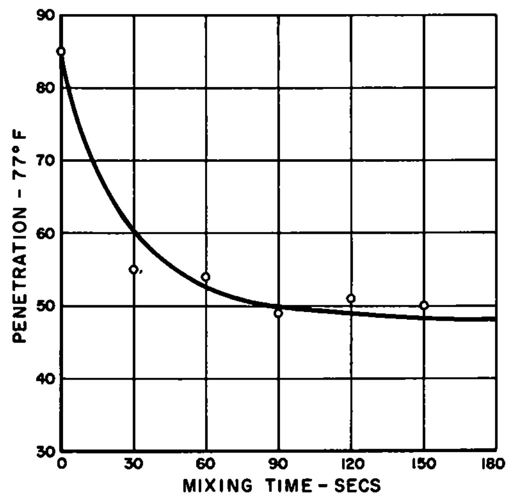

Figure 2. Penetration vs. mixing time, plant-mixed bituminous concrete (from J. G. Schaub and W. K. Parr, Proc. Montana Bituminous Conf., Sept. 1939).

to abrasion in the mixture prepared at 345 F compared to the one mixed at 270 F.

Thus far, the effects on the asphalt during the relatively brief mixing periods at elevated temperatures have been considered. It is also known that asphalts harden after the mixture is placed on the road, but in most regions it is not often that the temperature of the pavement will exceed 140 F. Figure 5 shows four curves where the abrasion loss is plotted against the curing time in hours at 140 F. This curing time is intended to simulate hardening conditions on the road. These curves show

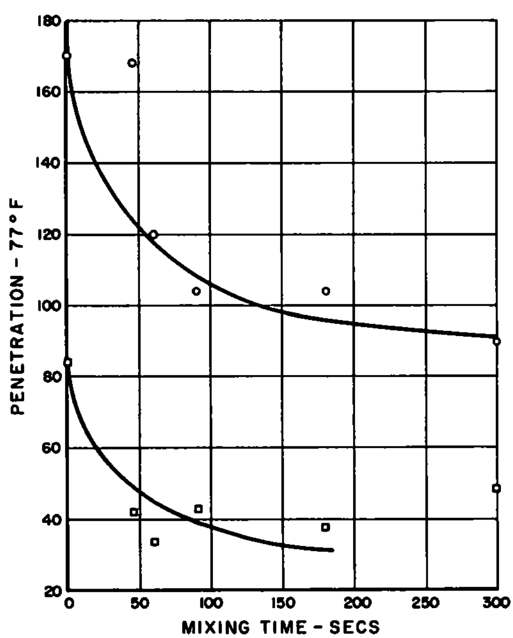

Figure 3. Penetration vs. mixing time VI - kern - 4 - C both asphalts from same production source sampled from field mixer.

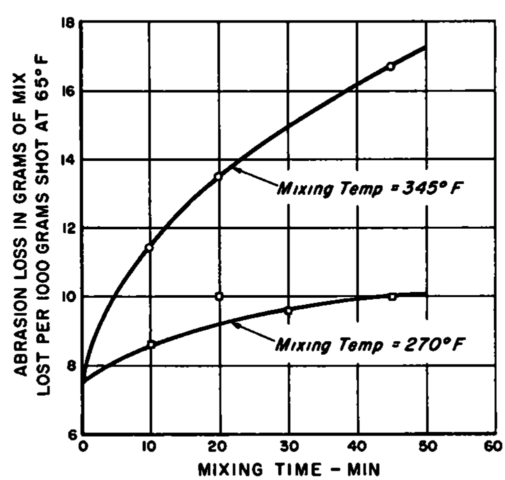

Figure 4. Relation between abrasion loss and mixing temperature laboratory mixer asphalt A, 85-100 grade.

clearly that the rate of hardening under atmospheric temperatures after mixing is virtually unaffected by the amount of hardening developed during the mixing cycle. More extensive studies have confirmed the evidence that there is no fixed relationship between the susceptibility of asphalts in the mixer at high temperatures and the changes that may take place on the road at atmospheric temperatures.

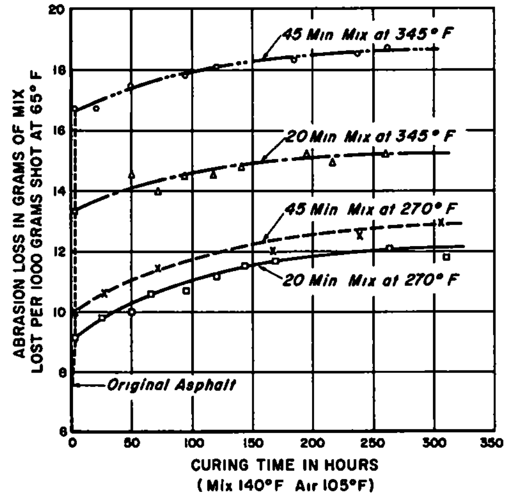

Figure 5. Weathering curves for the same asphalt mixed with Ottawa sand for various times and temperatures in a laboratory mixer asphalt A, 85-100 grade.

Discussion

W. B. Warden, Miller-Warden Associates, Swarthmore, Pa. — I concur with the data and our information supports it.

This matter of just what 75 sec and 150 sec means, and how realistic these limits are, has never really been answered. A research program for that purpose has been suggested to a group in North Carolina, and it is hoped that over this next year some facts will be evidenced to show the relative validity of both the 75 and the 150 limits.

Have you considered when we talk about the viscosity required for mixing that the filler has a great deal of effect? There is the so-called balling effect, or the fact that the asphalt first picks up the fines in a mix, creating a filler mastic or mortar. Coarse aggregate is coated with this mortar, not asphalt.

It takes but little filler to increase the viscosity of asphalt tremendously. A great deal depends on the nature and fineness of the filler, and some observations along those lines are to be presented at the AAPT meeting in Denver. When considering just what viscosity is optimum for mixing, the filler variable must not be overlooked.

In regard to mixing time, the data show that from a quality viewpoint the damage is done very rapidly at any given temperature. Therefore, from a quality viewpoint, it would seem that mixing time is not as important as temperature.

On the other hand, in Figure 5 there was considerable difference under properly controlled conditions, showing that there is a time effect. It is logical from this fundamental concept that this reaction should be a time-temperature reaction. However, mixing time is an important factor from an economic viewpoint in addition to the direct expense of additional power, heat loss, labor, etc., the amount of production time itself can be significant. A difference of 10 seconds mixing time on an ordinary 3-ton mixer can amount to a difference in production of 350 tons per 10-hr day. With a 100-day normal production season, that amounts to 35,000 tons per season or enough to pave 23 mi of 24 ft wide, bituminous concrete, 2 in. thick. Therefore, mixing time can be a very important consideration and should be held to a minimum, commensurate with the proper coating of the aggregate.

Mr. Griffith, The Asphalt Institute. — Mr. Warden introduced one concept that may be a little misleading, and that is in the filler being taken up with the asphalt. There is usually a dry mixing compartment in which the filler and asphalt mix together. It seems inconceivable that the filler immediately lodges on all of the aggregate and coats it from that point on. I think it is not nearly as severe as pictured.

Mr. Warden. — Some very careful work recently conducted by Barber-Green shows that the balling effect is real. Balls of mortar as big as one's thumb or as big as a walnut can be separated from the mix after only 5 to 10 sec mixing, with the larger particles essentially uncoated and the bulk of the asphalt tied up by the fines.

There is additional support for this concept in the laws of probability. The surfaced area of the minus 200 particles in a normal surface mix will amount to about 70 percent of the total surface area of all the aggregate in the mix. The surface area of the minus 10 material will amount to about 90 percent of the total surface area of all the mineral aggregate present.

Therefore, through the laws of statistics, it is probable that the greatest area coated would be the most prevalent area, which would be the fine material, and we have observed it from test.

Mr. Hveem. — One of the things observed in the West is the experience of mixing aggregates with liquid asphalt similar to SC-2 where the asphalt contents were often very low, as little at 3 percent by weight. In all of the cases where there was a deficiency in the amount of liquid asphalt, it was observed that the fines in the pug mill pick up the asphalt and get coated first. Therefore, I support Mr. Warden's statement; and this means that at some stage in the mixing there is actually a heavier coating on the fine particles than on the coarse.

For some years I have been having a controversy with Harry Nevitt, who insists that each particle in the mixture takes on a coat of asphalt proportional to the particle size or diameter. He has mathematical expressions to demonstrate how this must be true but as I do not understand mathematics I do not believe it.

Nevertheless, I think Warden has brought up an important point. His point is that the introduction of filler increases the viscosity of the asphalt. Therefore, as the filler is incorporated in the asphalt you will have a much more viscous liquid to be spread over the coarser particles.

I think that this practice in the East of first dry mixing and then wet mixing is an economic waste. So far as I know, in the West there is no dry mixing. The aggregate and filler is dropped in the mixer, followed immediately by the asphalt, and I question the need for this dry mixing operation.

An extra 10 seconds in the mixer is an important matter so far as mixing costs are concerned and anyone ought to study the results very carefully to see whether dry mixing is necessary before any money is spent for it.

Mr. Warden. — With respect to the discussion on the pros and cons of dry mixing, we feel that the primary purpose of dry mixing is to heat the added mineral filler by giving it some time for contact with the hot aggregate from the bins prior to the asphalt addition. Thus we have long recommended a dry mix time of about ten seconds for surface course or other mixes containing an appreciable amount of added mineral filler but no dry mix time for binder course or other mixes which normally do not involve the incorporation of cold added mineral filler.

We, therefore, find ourselves in an intermediate position between West Coast practice and East Coast practice, basing our recommended operating procedure on the requirements of the mix rather than on location.

Bruce Weetman, The Texas Company. — Mr. Hveem showed the effects of mixing time on asphalt hardening. What is the consideration given to the hardening in the truck, and then transportation to the road? I am talking about a minimum in the mixer, and yet the mixture stays in the truck for 35 or 40 min before it gets to the road and is spread.

Mr. Hveem. — Well, actually, I have no definite data which will answer your question. We have recovered asphalt from mixtures taken from the road but there was no evidence of continued hardening which is assumed to be due to the fact that the bulk of the material is enclosed in a mass and is considerably away from air. This is a conclusion based on observation and is somewhat in the form of a supposition as the mixture has not been followed step-by-step from the plant to the finished road surface.

Mr. Weetman. — We have data that tend to confirm that particular point.

Mr. Hveem. — This is a question of the proper setting or establishment of the mixing temperature. How are you going to fix a standard mixing temperature for asphalt plants where in one case you are mixing in the middle of the summer with the thermometer around 100 F and in another case in the late fall (when you should not be doing the work anyhow)—how can you employ the same temperatures for such widely varying conditions? In our case, all that can be done is to instruct the field men to mix at the lowest possible temperature—and hope that they will do it.

Mr. Weetman. — Mr. Warden was advocating minimum mixing, and I would like to put in a word of caution against it. You have seen roads that used the minimum mixture temperature (that is, 30 seconds total mixing), and looked fairly good, but just went to pieces, primarily on account of the low mixing temperature.

I would rather sacrifice 1 or even 10 points of penetration to get a good road, and a poor mix has not performed satisfactorily in service.

Mr. Warden. — You raised the point on which we do not have sufficient data. On the other hand, it must be recognized that stripping phenomena are subject to many additional factors—the nature of the aggregate, the nature of the asphalt, whether or not an additive is being used, etc.

In a discussion with Mr. Hveem, I offered the concept that when the coarse aggregate is coated, the mix is properly mixed. He said: "Why wait for the coarse aggregate to be coated?" He has laid materials where the aggregate is not coated in the mixer, but was coated by the time the material was down for a day. He said, "We cannot see any difference in performance."

My point is that in this matter of adhesion with respect to stripping resistance, we have to take into consideration a great many other points.

Mr. Campen. — Mr. Hveem in his part of the discussion made the statement that it is not necessary to coat all the aggregate in the mixer, because the lay down operations will finish the mixing. I am in complete disagreement with the statement. The lay down operations do not accomplish any intimate mixing; that is, they do not disperse the asphaltic cement on the surfaces of the aggregates.

The lack of asphalt on the surface of the larger particles (the larger particles coat less easily than the smaller ones) is due to one of two reasons. Either the asphaltic content is too low or the particles are not dry. The former condition can be corrected by adding more asphalt. The only safe way to correct the latter condition is to continue the mixing until the aggregate particles are dry. If complete drying cannot be accomplished in the mixer, either the dryer will have to be made more efficient or the aggregate rejected.

The lack of proper coating in the mixer is an indication of improper conditions. Therefore, rather than expect the lay down operations to do the impossible, it is much better practice to find the source of the trouble and take steps to correct it. It is much more economical to spend a little more in preparing the mixture than to maintain the pavement thereafter.

Ward K. Parr. — We find an insignificant loss in penetration during the hauling period. You have the area of the air penetration, and it is typical from your time of mixing curve that you would assume that, and we find that to be very true.

Gene Abson, Chicago Testing Laboratory. — I think in answer to one of Mr. Hveem's statements that the dry mixing requirement has been the result of experience over a great many years. Normally, 35 or 40 years ago, sheet asphalt mixes were prepared in open pugmill mixes, and frequently the asphalt was added to the sand and then the filler dumped in, in order to avoid the dust incident, and as a result of experience gained by observation, it was found that dry mixing certainly did not augment the quality and the perfection of the mixtures.

I think that is the reason for the dry mixes.

One other thing in reference to what Mr. Warden said—I think the percentage of filler, in addition to the fineness, has a great effect on the temperature required. The temperature required was extremely high, even though it may have caused deterioration of the asphalt, but necessarily on account of the very thin films of asphalt.

The viscosity played a less important part than the requirement of film thickness.

T.K. Miles, Shell Oil Company. — I want to discuss Mr. Hveem's point about the difference in the mechanism of hardening of asphalt at about 165F.

We were concerned with this microfilm durability test for the hardening of asphalt. Initially we ran the test at 120F merely because this simulated the maximum temperatures, and we thought that range was involved on a road on a warm day. This worked out fine except that it took quite a while to harden the specimens in the oven.

We thought that possibly we could speed up the temperature. Therefore, we ran a whole series on a large number of asphalts available to us, varying the temperature from 140F to 150F. With the asphalts thus tested there was no difference in the way one would rate their hardening at temperatures of 140F to as high as 250F.

Perhaps that does not exactly state that there is no difference in the mechanism of hardening. On the other hand, there was no crossover—no asphalt that looked better at one temperature and worse at another.

We felt justified in using a higher temperature (225F) because we could obtain the same amount of hardening in two hours that we could at fourteen.

Mr. Foster. — The inference that the hardening occurs in the truck is not true. We have asphalt plants as far as 50 mi from the job, and there is no particular hardening curve.

I do not think the asphalt plant should be as far away from the contractor as the asphalt plant would like to be.

Mr. Hveem. — We take the view that the Lewis Thin Film Test, if at all significant, can only be expected to correlate with the hardening in the mixer. I do not think that it should be used to predict hardening on the road. We agree thoroughly that testing of asphalts should be performed in the thin film state but films ⅛ in. thick are not very thin.

We are now working with a Thin Film apparatus of our own with which it is hoped to develop the same type of hardening as occurs in an asphalt plant but which should require much less than 5 hr heating.

The Effects of Pugmill Structure and Asphalt Spraying Mechanism on the Mixing and Properties of the Mixture

J. F. TRIBBLE, Alabama State Highway Department

●THE MIXING system of the conventional asphalt paving materials mixer has not changed much in seventy years. There remain in use the batch and continuous types, but in both the mixing itself is in a twin-shaft pug mill.

The impact type or a fast modification of it, is pressing for a place in today's construction. Engineers will first have to be sold on the potentialities of both its product and production for it to become required equipment on paving contracts. Very few contractors will buy it as merely permitted equipment.

A passing note may be made of a closed rotary drum type of mixer that was in limited use throughout the South prior to World War II and is still permitted by Alabama Specifications. It is mentioned because by means of compressed air it too charged a mist of asphalt into the cascading aggregates inside the rotating drum. It made a whole truck load at a batch, six or more tons, but it required several minutes, a lot of clamping and bolting and other cumbersome operations, and use of a very heavy plant. In spite of the fact that the asphalt in the very hot mix had to absorb the hardening effects of the compressed air, it did produce materials for some very excellent pavements, especially sand-asphalt and sheet asphalt pavements.

A specification writer today elaborates on various details of the required plant, but makes only scant reference to the mixer itself. It is taken for granted much like the engine in the sales description of the new automobiles. Many words are used to describe the windshield, seats, trunk, fenders, etc., but only two lines cover its vitals.

The specification writer claims he is specifying required results and leaving mechanical features open for development. The developer on the other hand counter claims there is no real need to offer improvements unless they carry with them inducements for the customer to buy new mixers. For a mixer unit, features like lower power and maintenance requirements, easier charging and discharging, adjustability, and a better mixed product can never offer an inducement to buy that will match one like bigger batches and more of them per hour.

More and bigger batches per hour, after all of the lost motion in batching is absorbed, means stretching mixer efficiency and trimming the total dry and wet mixing time. That is where the specification writer and the equipment supplier, each with an interest to defend, conflict. The specification must protect against use of the relics and insure a good mix from the average and better plant in use in the area. With over-all considerations the specifier cannot suddenly rule out all but the very newest units. Because both traditionally and currently, mixing time is the only reliable measure of mix control available one is faced with the choice of a time cycle that will not sacrifice quality of mix from one plant, but may limit production capacity from another.

If there were some nationally established method of rating effectiveness of mixing, the mixing time requirements could be eliminated, but as things stand now, it takes very little imagination to visualize the confusion that would exist should one make and model of plant be allowed an acceptable mixing time of 25 sec, another 35 sec, and a third 45 sec.

In cement concrete paving work, often with the same paver, there is such a wide variety of mixing volume and mixing time requirements in all of the states that a national experimental study is being conducted by Bureau of Public Roads to try to settle on uniformity in such requirements. Over twenty states have agreed to participate. Similar work is under way in the field of mixing for bituminous pavements. A report may be made on it next year, and it is hoped that it will provide a usable rating method.

The only mixing rating now available is loaded with human element. The inspector judges the mix to be satisfactory when the asphalt is evenly dispersed through the mortar, when there are no balls of too much or too little asphalt, when the coarsest particles appear completely coated and when the mass has a uniformly fluffy texture with a slightly glossy appearance. The contractor may be fully willing for his product to be accepted on such a basis, but if it is rejected, he may feel a need for something more substantial than personal opinion. The inspector may listen to a long argument about the dangers of damage from over-mixing and may also begin to feel insecure in his rulings. There is, of course, some scientific support for accelerated hardening of hot asphalt by aeration, but with a difference of a few seconds, the use of the fact as "scare talk" is doing more damage then hardened asphalt in the mix.

The pug mill itself, after it has once turned out a satisfactory mix, is then accepted on faith—and why not? It is a relatively simple machine with a simple function to perform. It distributed fines by dry mixing. The fines immediately catch the hot asphalt when it is introduced and are glued together. The tossing and scouring action of the paddles "unglue" the mortar and knead it over the surface and into the voids of the coarse aggregates with a little air to make the mass into a black concrete. The mechanical action of the performance is something that after long research is manufactured into the mill. Some makes are strong in one feature and others in another. The power supplied the arm length, size, setting and speed of rotation of the paddles, lining clearance and arrangement for discharge are features that, good or bad, are built into the mill as are the various means for charging aggregates and asphalt. The operator can maintain it in near factory condition and make a few minor adjustments in paddle settings to avoid segregation, but after that, results will depend upon using proper materials and following a fixed sequence.

Let it be remembered, however, that when a desirable product leaves the pug mill much can happen to it before it becomes a pavement.

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 4½ 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

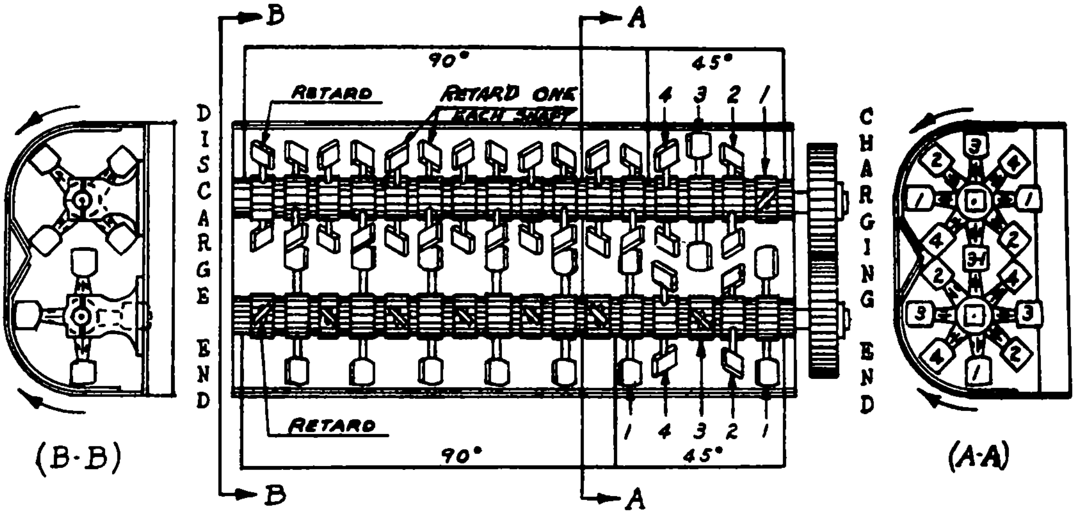

Figure 1. Paddle arrangement for continuous mixers for materials difficult to mix.

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.

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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.

Effect of Mix Temperature

CHARLES F. PARKER, Chief Engineer, W.H. Hinman, Inc., Westbrook, Maine

●THE EFFECT of temperature of mix, or viscosity of asphalt, has long been known to have a great influence on the compaction of bituminous concrete mixtures. Modern pavers are now equipped with compaction devices which do much in obtaining initial compaction.

The laboratory has been studying compaction of bituminous mixtures for many years, especially compaction at various temperatures. Attempts were made to obtain cores from actual pavement construction that were constructed at various temperatures. However, there were so many variables that results showed poor correlation. It was found that when compaction temperatures were in the range of 275 F the densities obtained closely approached the density obtained with the Marshall compaction method. For that reason it was decided that a study of compaction temperatures could be conducted at a higher degree of correlation when compacted in a laboratory by the Marshall Method than by cores from actual pavement construction. This study was conducted on both a surface mix and a binder mix in accordance with Table 1.

TABLE 1

Sieve	Percent Passing: Binder Course	Percent Passing: Surface Course
¾ in.	100	
½ in.		100
No. 4	30.5	68.3
No. 10	24.5	44.4
No. 20	20.3	31.6
No. 40	15.1	23.0
No. 80	8.5	13.9
No. 200	3.1	4.7
Asphalt % of Mix (85/100 Penetration)	5.1	6.3

Several methods were studied for evaluating the data from this experiment and it was felt that if it were assumed that ideal conditions would have been attained if the compaction was at 275 F then all other values could be shown in terms of the percent obtained at 275 F.

Specific Gravity

Figure 1 shows the relationship of specific gravity to the compaction temperature. This is based on 100 percent at a compaction temperature of 275 F. Although there is a reduction almost immediately, rapid loss starts at a temperature of 225 F. This indicates that compaction should largely have been accomplished before the temperature was below 225 F and while the mix is still in a plastic state.

Figure 2 shows a similar relationship for the binder mix. This relationship is very similar to that for the wearing course. However, the compaction temperature is not nearly as critical in the lower range as that shown for the wearing course.

Percent Voids

Figure 3 shows the relationship of percent voids to the compaction temperature based on 100 percent at a compaction temperature of 275 F. This chart is a striking example of what occurs when the mixture is rolled at too cold a temperature and largely accounts for the difficulties in fall paving in northern climates. There is only a slight reduction of voids at temperatures of 300 F and 350 F. However, at 200 F the voids have doubled and at 150 F they have increased four times, while at 125 F the voids have increased over six times the value obtained at 275 F. This shows that the danger of cold weather construction lies in the ability to accomplish a maximum amount of compaction before the temperature of the mix has reached 225 F.

Figure 4 shows similar results for the binder mix. Although there is a similar increase in void content when compacted at various temperatures the results are not nearly as critical as with the finer surface mixture.

Marshall Stability

Figure 5 shows the relationship of the stability value from mixtures compacted at various temperatures. These mixtures were all tested at the standard temperature of 140 F. The results, as in other cases, are based on a 100 percent value with a compaction temperature of 275 F. This experiment indicated that the stability of the mixtures would be increased about 20 percent if the compaction temperature was above 300 F. This would, of course, be related to the viscosity of the asphalt which in this case was an 85 to 100 penetration grade. The stability falls rapidly when the compaction temperature goes below 250 F. At 150 F less than 20 percent of the value at 275 F was obtained.

Figure 6 shows similar results for the binder mix and there is a remarkable similarity between the results obtained by the Marshall Method on both the binder and surface mixtures.

Hveem Stabilometer Values

Figure 7 shows the relationship of the Hveem Stabilometer values on mixtures compacted by the Marshall Method at various compaction temperatures and tested at the standard temperature of 140 F in accordance with the standard Hveem stability test. This chart indicates that with this method of compaction the

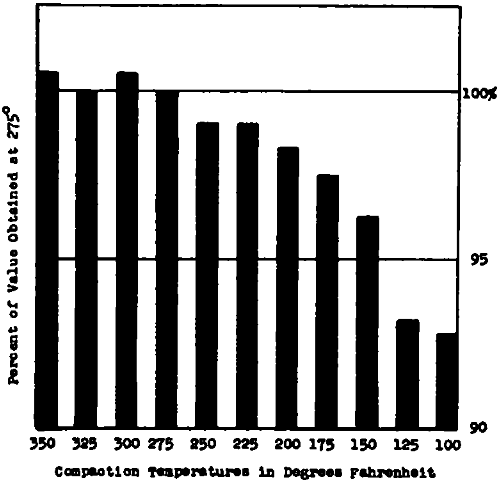

Figure 1. Bituminous concrete wearing course specific gravity. Effect of Marshall compaction at various temperatures.

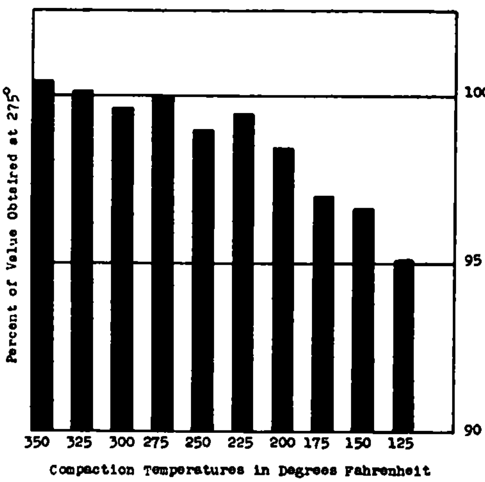

Figure 2. Bituminous concrete binder course specific gravity. Effect of Marshall compaction at various temperatures.

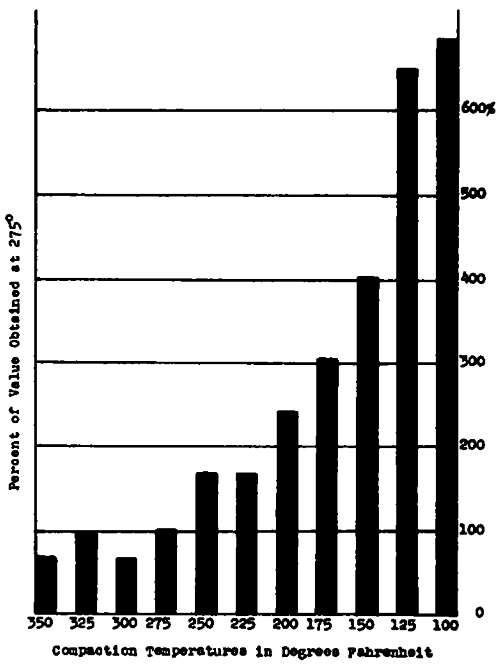

Figure 3. Bituminous concrete wearing course percent voids. Effect of Marshall compaction at various temperatures.

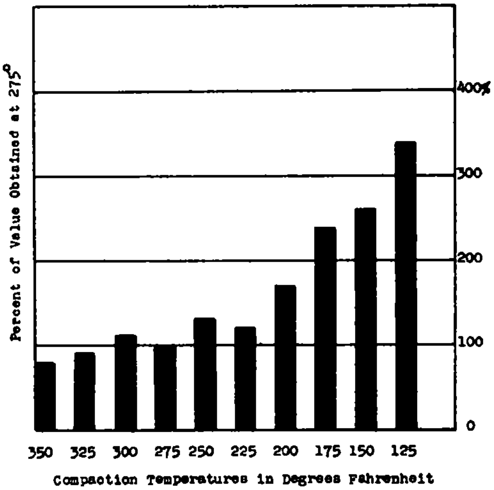

Figure 4. Bituminous concrete binder course percent voids. Effect of Marshall compaction at various temperatures.

compaction temperature is not as critical as with the Marshall stability values. An increase in stabilometer values was obtained at lower temperatures than 275 F and a fast drop off occurred below 225 F.

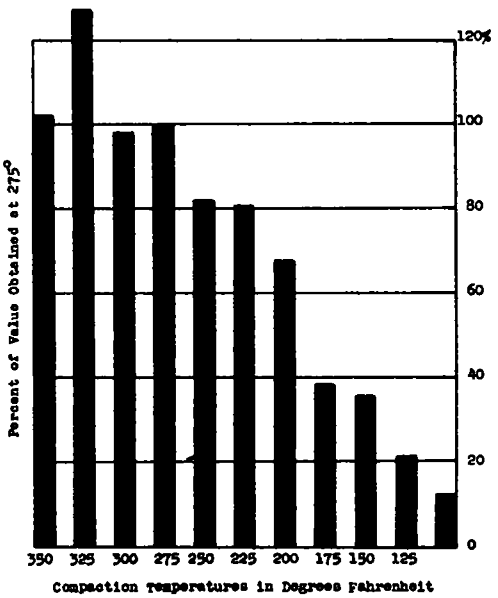

Figure 6. Bituminous concrete binder course Marshall stability. Effect of Marshall compaction at various temperatures.

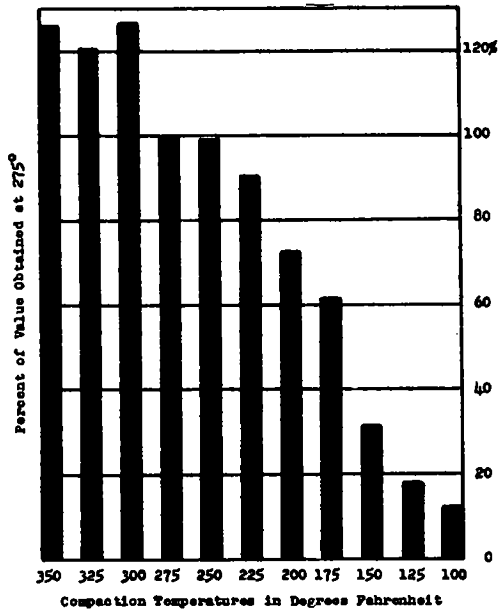

Figure 5. Bituminous concrete wearing course Marshall stability. Effect of Marshall compaction at various temperatures.

Figure 8 shows a similar study with the Hveem Stabilometer for the binder mixture. The characteristics of the curve with the binder mixture are radically different from those obtained with the finer wearing course mixture. The maximum result was obtained at 350 F and there was nearly a straightline relationship in the drop from the maximum temperature to the low temperature of 125 F.

General

All of these tests indicated the importance of compaction at high temperatures. A practical example of results that were obtained under actual pavement construction when compaction was at a low temperature is shown in Figure 9. This pavement was constructed in the fall during cold temperatures and the resulting density was very low. Extractions showed that the mix was well within tolerance limits. However, due to the low density and late fall construction which did not permit any further compaction by traffic, this raveling occurred during the winter months. Cores taken the following year also showed the same low densities.

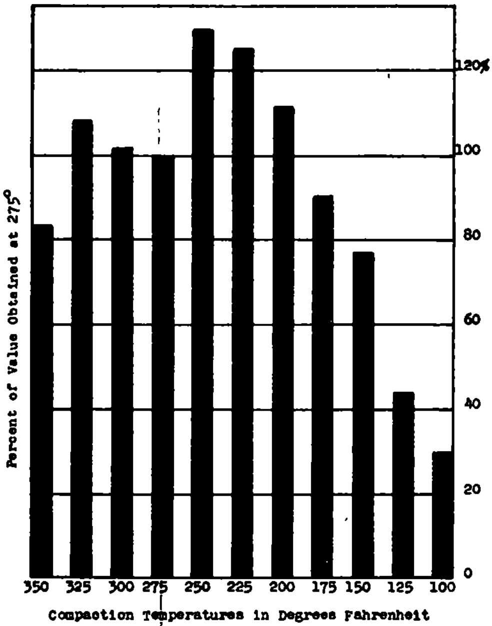

Figure 7. Bituminous concrete wearing course Hveem stabilometer values. Effect of Marshall compaction at various temperatures.

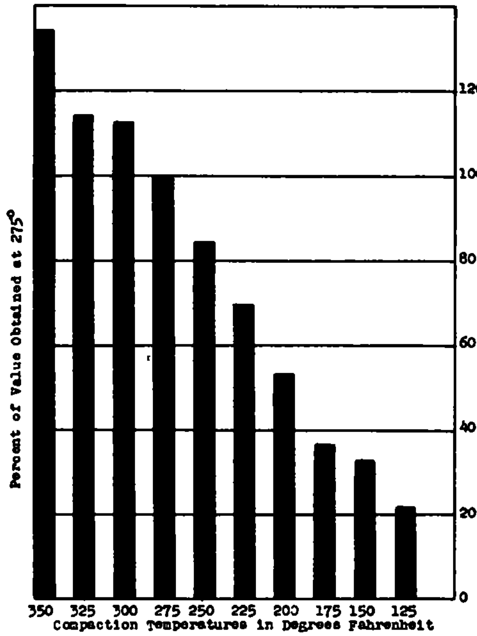

Figure 8. Bituminous concrete binder course Hveem stabilometer values. Effect of Marshall compaction at various temperatures.

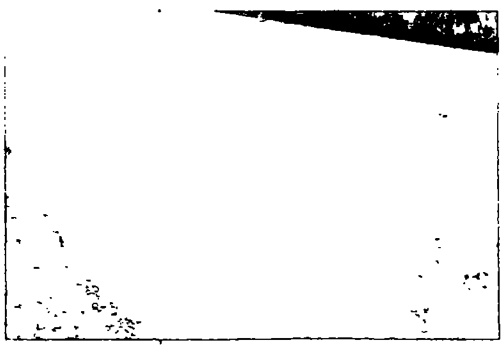

Figure 9.

Compaction

The author has long advocated the use of large diameter rolls on steel tired rollers. With an increase in the diameter of the rolls there would be less horizontal thrust and this would permit compaction at higher temperatures without lateral displacement of the bituminous concrete mixture. Many cases have been observed in which there was a lack of stability in the gravel base courses due to the use of a granular non-plastic material and in such cases many difficulties were encountered in placing the binder course directly on the gravel base course. It has been observed many times that this binder course has been permitted to lose a high percent of its mixing temperature in order that rolling could be accomplished without lateral displacement. By increas- the diameter of the steel tired rollers, even when such unstable conditions did exist, rolling could be accomplished at a much higher temperature without any lateral displacement.

Several years ago the Buffalo-Springfield Roller Co. conducted an experiment

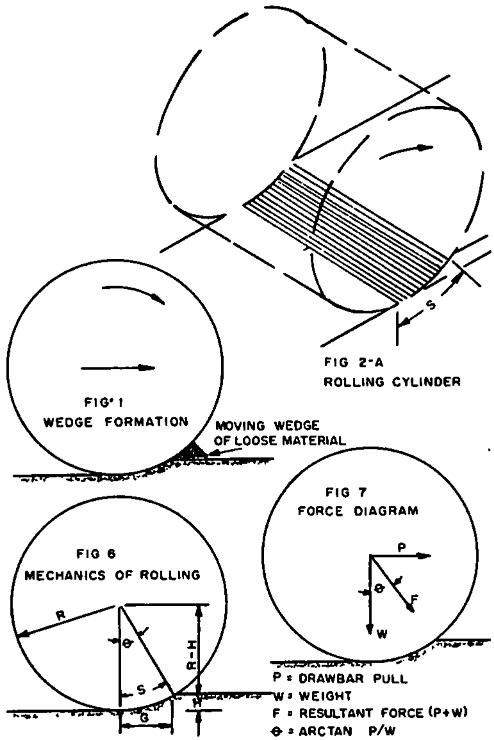

Figure 10.

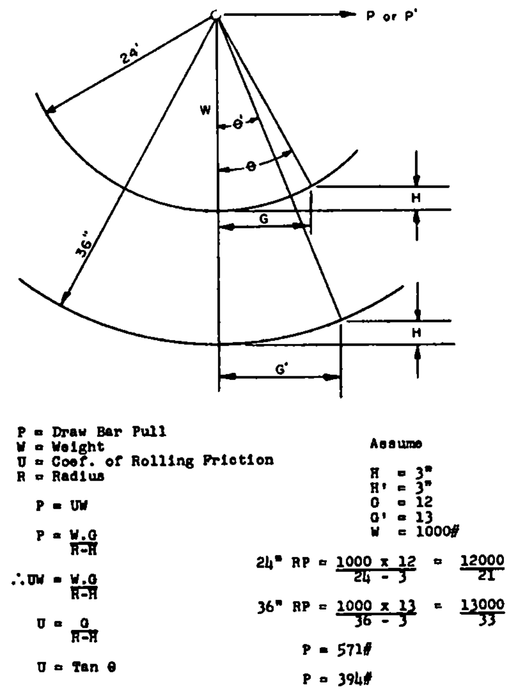

Figure 11. Mathematical analysis of rolling.

on drawbar pull. In this experiment a roll of 46-in. diameter and weight of 3,280 lb was used in conjunction with a hydraulic dynamometer to determine the coefficients of various materials. The coefficients obtained were in accordance with the following:

Weight = 3,280 lb

By Experiment, Using Hydraulic Dynamometer, 46-in. Dia. Roll	Coeff.
Bituminous concrete, compacted	0.27
Oiled clay, compacted	0.46
Sandy clay, loose surface	0.30
Untreated macadam	0.27

Using these coefficients the drawbar pull was computed theoretically for 53-60- and 72-in. diameters. A mathematical analysis of this computation is shown in Figures 10 and 11.

Figure 12 shows the relationship of the drawbar pull to the diameter of the rolls for various types of materials. With all

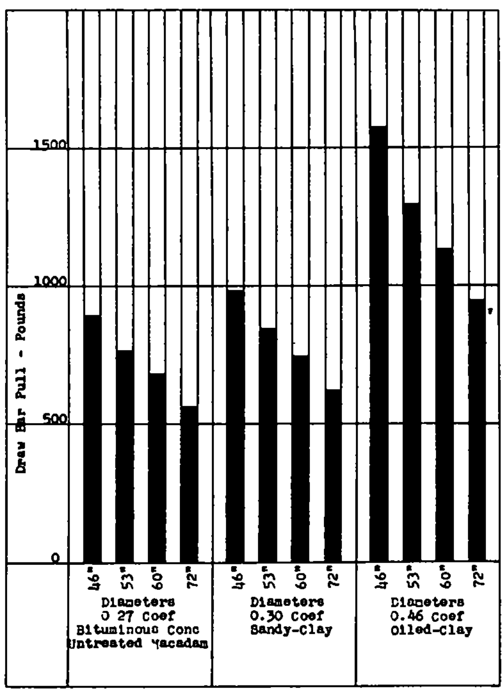

Figure 12. Draw bar pull—various diameters and conditions.

of the materials there is a rapid drop in drawbar pull with slight increases in the diameter of the rolls. This is what largely accounts for the ability to roll bituminous mixtures at higher temperatures when there is an increase in the diameter of the rolls. If these diameters were increased there would be a necessary increase in the weight of the rollers which would have to be compensated for by increasing the width of the roll. This would also be a distinct advantage as it would increase the capacity of the roller in terms of square yards rolled per unit of time. This increase in the rate of rolling would in turn be reflected in the ability to roll at higher temperatures as the rolling procedure could be completed in a much shorter interval of time. This is illustrated by Figure 13 in which the percent of value obtained with a 6-in. lap as compared with the result obtained when the lap is reduced to ⅓ W and ½ W for both a 54-in. width roll and a 60-in. width roll. This chart indicates that it is entirely possible that if the diameter of the rolls were increased and the width also increased within reasonable limitations, the rolling capacity in square yards per hour would be greatly increased for the larger type roller, resulting in initial compaction at higher temperatures and a much faster rate.

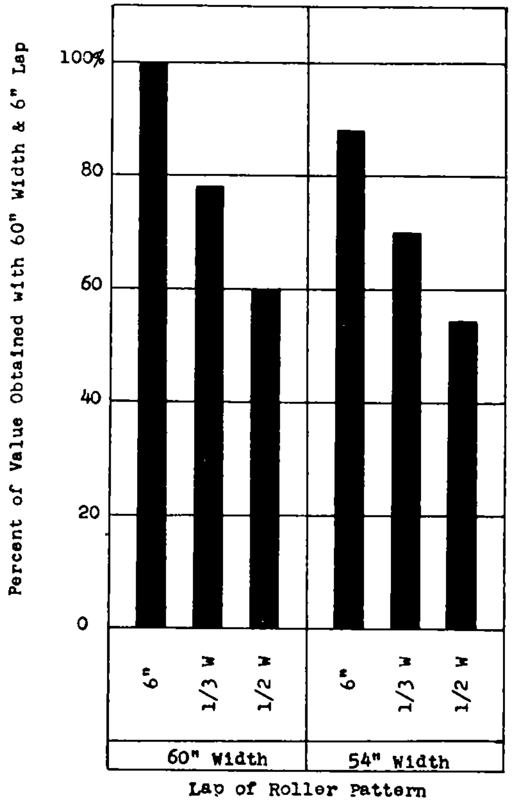

Figure 13. Percent square yards rolled per hour two coverages.

Conclusion

Not enough attention has been given to the compaction temperatures. It is believed that a much more practical limitation on the construction season in northern climates would be to specify rolling temperatures together with seasonal limitations than by merely limiting the paving season to calendar dates.

Effect of Mix Temperature

F. W. KIMBLE, Flexible Pavements Engineer, Ohio Department of Highways

● HOT MIX asphaltic concrete should be laid at the lowest mix temperature which will enable securing the specified or desired result in the completed pavement. For asphalts from different sources, this temperature will vary over a considerable range. For asphalts from the same source of different penetration ranges, the minimum satisfactory laying temperature is usually higher for the more viscous asphalts.

Because of its thermoplastic nature, asphalt cement decreases in viscosity with increase in temperature. For asphalt cements of the same penetration range, the relationship between temperature and viscosity is more often not the same for asphalt cements from different sources. Because of this situation, mixing and laying temperatures in most specifications are set at broad ranges rather than narrow ranges. It appears there would be a great deal of advantage for the supplier or user to determine the temperature-viscosity relationship of asphalt cements so that optimum mix temperature can be set for a particular mix.

Coarse aggregate mixes can be mixed and laid at lower temperatures than fine aggregate mixes. This means that for both mixing and laying, the asphalt cement must be at a lower viscosity for the finer mixes.

Since proper placing of the mix in the course has a bearing on the compaction secured, with a given compactive effort, something should be said concerning this important operation. The components of a paver which come into contact with the asphalt mix should be pre-heated to and maintained at or near the mix temperature. This is also true for hand tools used to rake, shape and compact the mix, either in a hand operation or as a part of the regular paver operation. Failure to maintain the paver screed components at the mix temperature will result in scuffing of the surface and edges of the course. Scuffing is due to congealed mix adhering to the screed face and the screed skirts. Unless it is corrected, severe tearing of the surface of the course usually follows with the placing of a mat of widely varying density. A mat laid in this manner will cool more rapidly, making compaction more difficult.

Rolling or compaction of the course should be performed soon after it has been placed while the mix is at or near the optimum temperature for compaction. The timing of this operation depends upon the temperature of the supporting base and the atmosphere. In any event, the initial compaction or rolling of the mix is more properly performed as soon as possible after laying. Subsequent and finish rolling is then timed so this operation is completed before the mix has cooled to the point where the compactors are no longer effective. It has been found rubber-tired compactors enable more rapid finishing of courses with greater and more uniform density of the courses if the rubber-tired compactors have wheel loads and inflation pressures that enable securing contact pressures equal to or in excess of those exerted by the standard rollers.

In order to investigate the effect of mix temperature on compaction or field density, this study was made in Ohio some years ago in conjunction with other factors affecting field density. The test was made during July 1952, on a project where the nominal maximum particle size of the coarse aggregate is ¾ in. with a compacted course thickness of 1½ in. The aggregates were limestone and limestone sand and the asphalt cement 70-80 penetration range. At mid-day, mix temperatures were varied from 250 F to 325 F in increments of 25 F. Three loads of 10 tons each were prepared and placed at each temperature. The same compactive effort was used for all test sections, which was in excess of the minimum required by specifications using standard steel-wheeled rollers. The compacted weight per cubic yard of this mix in place at the time of construction varied from 3,618 lb at 250 F to 3,709 lb at 325 F. These test sections were again sampled in August 1952 and December 1953 to determine gain in density due to traffic. This mix was placed on a heavily traveled road and it was found all test sections had the same density in August 1952, with a slight increase over the density secured at a mix temperature of 325 F. The December 1953 sampling showed all the test sections to have the same density, with an appreciable gain in density over the sampling in August 1952.

From the experimental work related above, it appears there is advantage in placing asphaltic concrete at optimum temperature. With standard rollers, greater density can be secured at the time of construction at an optimum temperature. It is desirable to secure greater density at the time of construction in order to minimize the increase in density due to traffic. Furthermore, it would be desirable to have a compactor that would enable securing ultimate traffic density at the time of construction.

The Effects of Air and Base Temperature on Compaction

VERDI ADAMS, Bituminous Research Engineer, Louisiana Department of Highways

● DURING THE past few years the extent of cold weather construction of hot mix asphaltic concrete pavement has shown considerable increase in Louisiana. Hot mix operations in the past were limited only by air temperature. This was not quite adequate. Excessive rutting resulted from low densities. In order to achieve proper compaction, in cold weather, it was considered necessary to investigate the effects of base temperature and correlate it with air temperature.

This investigation was carried out during January 1958 in central Louisiana on US 84. A surface course mix with ¾-in. maximum size aggregate was used and laid in two 2-in. layers on an old concrete roadway. Compaction was accomplished with a 10-ton 3-wheel roller; followed by a 10-ton tandem roller and the number of passes were closely controlled throughout the operation. Spreading and rolling temperatures were measured by means of thermocouples and a potentiometer. Base temperatures were taken with surface thermometers. These thermometers are 2 in. in diameter and can be carried in the pocket. A light application of silicon grease is used to insure a good contact with the surface. A complete set of data was thus obtained every 600 ft.

The completed test results, accumulated over a period of one year, show a definite relationship between air-base temperature and percentage of compaction. The roadway density is not affected by incremental increases in base temperature from 43 to 65 F for which the corresponding air temperatures are 41 and 50 F, respectively.

At a base temperature of 65 F the roadway density starts improving with temperature and reaches a maximum value of 95.2 percent at 80 F. Thus there is an increase of 3.0 percent by difference in the roadway density for this 15 deg interval. Additional increases in base temperature would have had no appreciable effect on density.

The critical point of the mixture under study is 77 F base temperature with a corresponding air temperature of 55 F. This preliminary inference was confirmed when a complete study of the pavement was made six months after completion. A second curve, representing the result of that survey for the density-temperature relationship follows the same pattern as the original. Comparison of the curves shows that after 6 months of use the base with temperature up to 75 F showed an increase of 2.8 percent in the roadway density. At 80 F the densification under traffic is only 1.1 percent. In other words, six months of traffic use had only one-third as much effect on the density of the sections compacted at 80 F base temperature as on those compacted at lower temperatures.

The shape of the curve represents Marshall stability-temperature relationship at the end of the 6-month period. The shape of this curve follows the same pattern as the density-temperature curve, proving that higher density, and thus higher stability, is obtained at base temperatures above 75 F. Of course, these results represent only one type of mixture and may not be indicative for others; it is, however, reasonable to expect the same general pattern with hot mixes of this type.

Whenever pneumatic rollers are used it is possible to use lower base temperatures. Plans have been made to investigate this aspect.

In addition to the density tests the rutting was measured every 6 months. Measurements were made for each section every 20 ft in both tire tracks. The rutting after 12 months is twice as much at a base temperature of 45 F as at 80 F. Furthermore, the differential rutting from 6 months to 12 months is appreciably higher at low temperatures than at higher temperatures.

During this entire study the base temperatures were always higher than air temperatures.

To establish an approximate relationship between the air and base temperatures under different weather conditions, an additional study was conducted. This study indicated that: (a) the air temperature never exceeds the base temperature although in cold and cloudy weather the base temperature is only slightly higher than air temperature; (b) base temperature of asphaltic concrete pavement is always higher than portland cement concrete pavement; and (c) on bright and sunny days the surface temperature of portland cement concrete pavement is normally 15 to 20 deg higher than the air temperature, and asphaltic concrete is 25 to 30 deg higher.

Although this study is by no means complete, the results obtained so far have been consistent. The recommended temperature of 75 F may seem a bit high, but the air temperature necessary to allow this critical base temperature is only in the middle 50's, as pointed out earlier, and that is not a rare recording in winter months in Louisiana.

Three more studies of this nature have been planned for 1959 in an attempt to study the feasibility of reducing base temperature requirements when pneumatic rollers are used in addition to steel-wheel rollers.

Discussion

Mr. Halstead.—The familiar suggestion has been made that mixing be done at a temperature at which there is a certain viscosity.

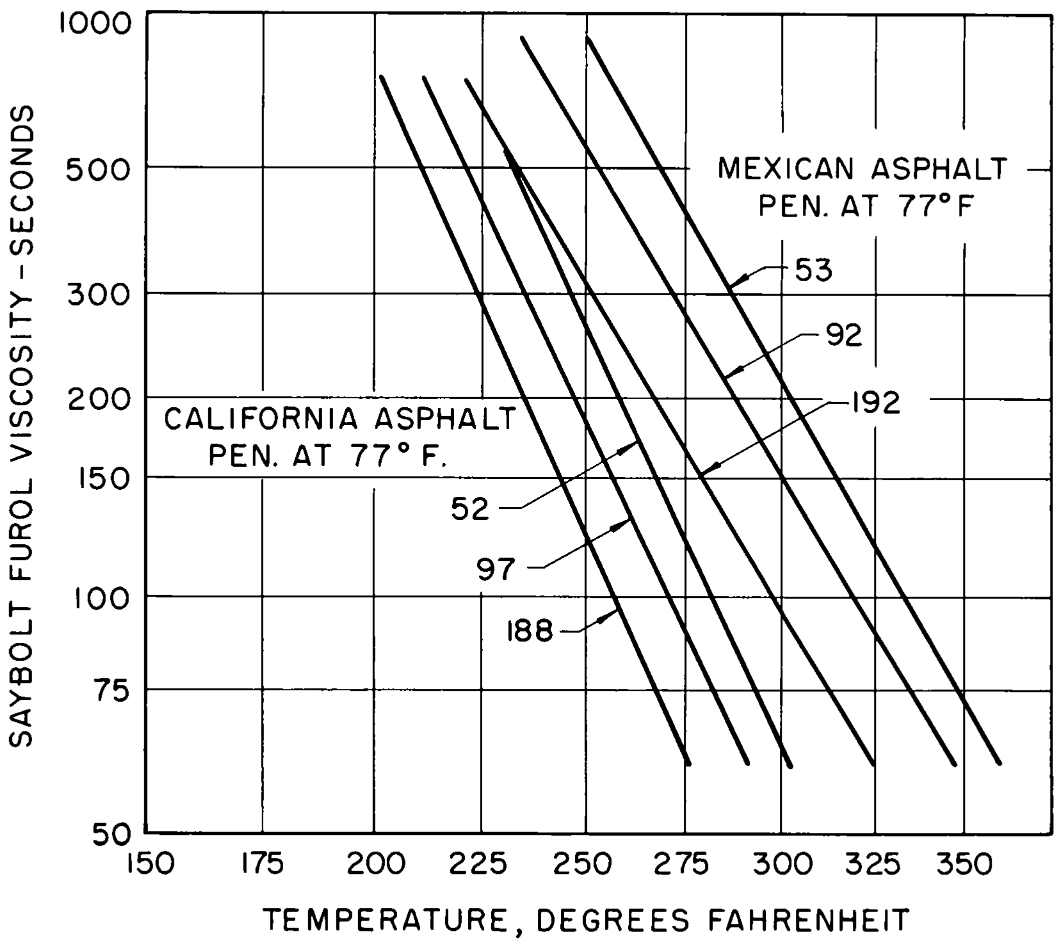

Figure 1.

So far not much has been said as to what this temperature is and how it is to be determined. One way, and perhaps the most accurate way of determining the temperature is to construct a chart showing the viscosity at various temperatures and determine from this, the temperature at the desired viscosity. Figure 1 illustrates some of the extremes that can occur in high temperature viscosities for the various grades of asphalts. Figure 2 is a chart for determining the proper mixing temperature for an asphalt from the Furol viscosity of the asphalt at 275 F.

Figure 1 is along the same lines as one of Mr. Griffith's, except that here is a

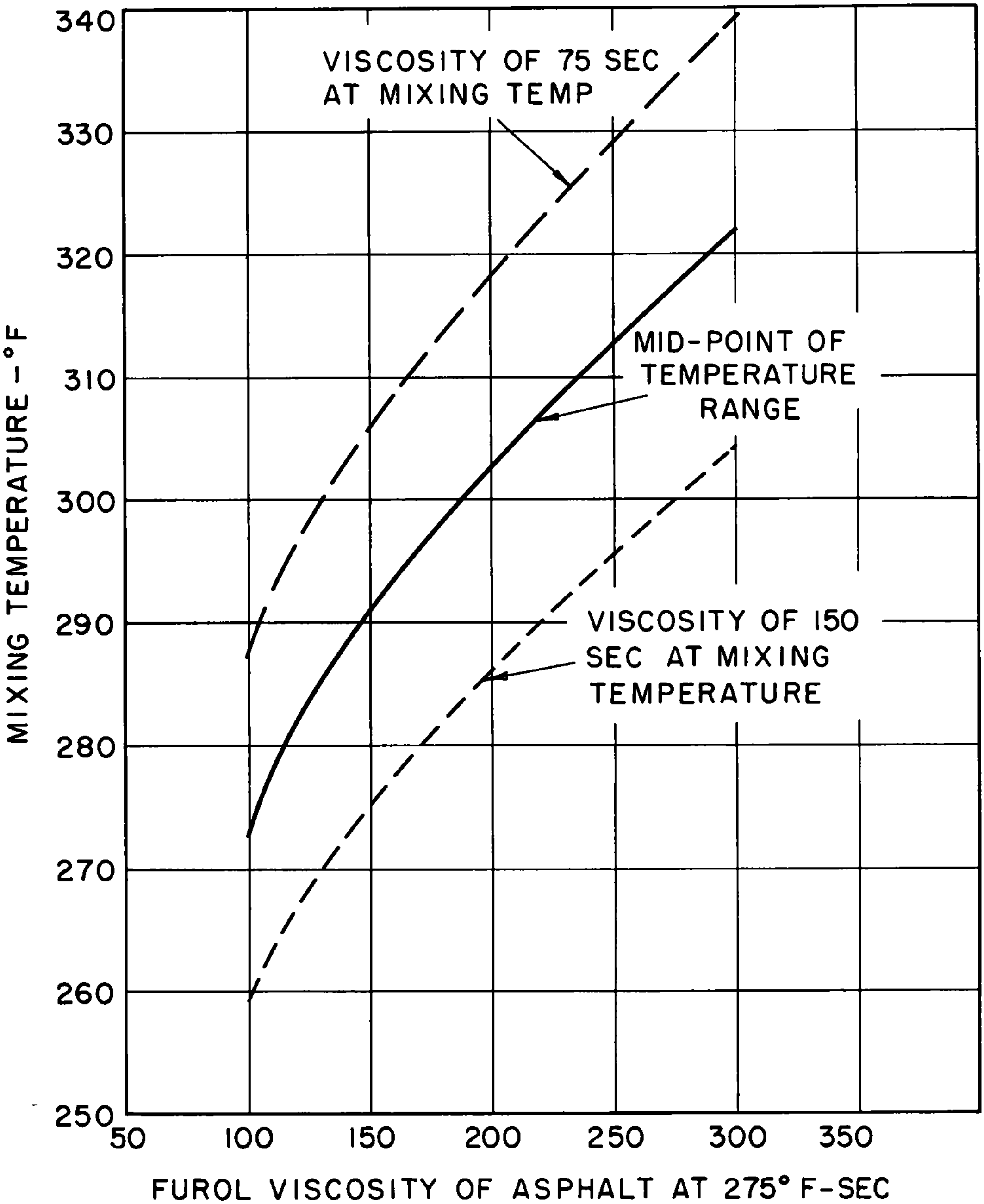

Figure 2.

selected group of asphalts whose viscosities are very susceptible to temperature change, and one group that has relatively low viscosity-temperature susceptibilities.

These two asphaltic types represent the extremes in commercial asphalts that are of good grade and meet all the standard specifications.

There are three grades for each type: 52 penetration, 97 penetration, and 188 for the California asphalt and 53, 92 and 192 penetration for the Mexican asphalt.

At 275 F, all of the grades of the Mexican asphalt have considerably higher viscosities than the corresponding California asphalt, but it is somewhat surprising to see that the hardest grade of California asphalt has a lower viscosity than the softest grade of the Mexican asphalt.

Considering only the curve for the 97 penetration California material and the curve for the 92 penetration Mexican material, the difference for the viscosity at 275 F represents the extreme difference for 85-100 penetration grade asphalts. By selecting samples having viscosities at 275 F intermediate between these two values, a family of curves can be constructed between these two extremes. Such data can then be used to construct a generalized curve that will come close to fitting all of the asphalts of the same grade.

Figure 2 was constructed from the generalized family of curves just described. The solid line, is the mid-point of the temperature range between that for a viscosity of 75 seconds and that for 150 seconds. This line thus represents the most desirable mixing temperature from the standpoint of viscosity for all asphalts of the 85-100 grade depending on its viscosity at 275 F. The data are cut off at the lower limit of 100 seconds and the upper limit of 300 seconds because it has been shown that most of the materials in the United States fall within this range.

The range in temperature between a viscosity of 75 and 150 seconds may be of interest to the practical minded man. It varies from about 30 F at the lower end to 35 F at the upper end.

Although the solid line shown here is the mid-point of the temperature range, it is very close to the curve that would be drawn for a viscosity of 100 seconds at the mixing temperature.

From a practical standpoint this chart makes it possible to choose the proper mixing temperature for the asphalt without having complete viscosity-temperature data. It is necessary to know only the Furol viscosity of the material at 275 F. If there are considerations that make it desirable to raise or lower the mixing temperature, the chart also indicates what the upper and lower limits of temperature can be and still remain within the range of 75 to 150 seconds.

It has been suggested that the upper limit of mixing viscosity be extended to 300 seconds. If that were done, the 150-second line (Fig. 2) would be very close to the mid-point of the temperature range. The over-all working range would then be approximately twice the range between the 75- and 150-second lines.

This chart was constructed from interpolated data. However, some checks were made against actual viscosity data and very good agreement was found. In some cases it is within 1 or 2 deg. The maximum difference noted was 9 deg low.

Mr. Griffith.— I think one thing brought out by your two families of curves is that you could run one viscosity value on the sample.

Mr. Collier.—As a practical matter, if you get out on a job and try to control viscosity to within 5 deg you are going to find a lot of opposition from the contractor, or a lot of rejected loads.

If we find we can control within plus or minus 10 deg that is considered good.

Only six sources of asphalt are used in my state, but by using the same process the same viscosity relationship results. Therefore we require knowledge of the type of asphalt used and we specify the limits of control.

Mr. Halstead.—I think that will be true in a number of states. These data were presented to illustrate to those not familiar with the concept of mixing according to viscosity, its effect in terms of mixing temperature—in other words, what changes would be required and how much control is needed to mix in the range between 75 and 150 seconds. Figure 2 shows the over-all range of temperatures needed for such control. It also shows that the degree of temperature control necessary to stay within the 75- to 150-second range is about the same as the minimum practical tolerance for plant operating temperatures. This is a point that is likely to be overlooked if we consider changes in viscosity values only. One is apt to look at the difference between 75 and 150 seconds, mentally calculate that this is a 100 percent change in viscosity, and think that this is very large. However, in terms of temperature differences necessary to cause this change, it is not really great. As a matter of fact, for a large number of asphalts the conditions necessary to control by viscosity are the same as the conditions set in many present specifications. The change really is not revolutionary.

HRB:OR-329

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Receiving funds from both public and private sources, by contribution, grant, or contract, the Academy and its Research Council thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The Highway Research Board was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the National Research Council. The Board is a cooperative organization of the highway technologists of America operating under the auspices of the Academy–Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the Board are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.

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