VISCOSITY IN HOT MIX CONSTRUCTION

BY
VERDI ADAM
BITUMINOUS RESEARCH ENGINEER

Prepared for presentation at the
18th Annual Convention of SASHO, November 1959

November 1959
Bituminous Research Unit
Testing & Research Section
Louisiana Department of Highways

THE IMPORTANCE OF VISCOSITY IN HOT MIX CONSTRUCTION

Viscosity, one of the oldest known and tested properties of Asphalt, yet one of the least studied is recently being given the attention it so rightfully deserves. Numerous engineers did recognize the importance of this property to the extent that several papers and magazine articles were written on the subject. Some of these pertaining to viscosity, only, indirectly, as the discussions were based on the effects of temperature in bituminous construction. The Asphalt institute, in 1958, recommended specific limits for viscosity to which the asphalts should be heated in order to achieve proper mixing. This certainly was one of the major achievements in hot mix construction.

Louisiana Department of Highways has been investigating the effects of viscosity of asphalts at several stages of construction on test results and performance of hot mix asphaltic concrete pavements since 1957. The information obtained so far, by no means is conclusive. However, the indications are that the degree of fluidity of the asphalt plays an important part during mixing and compaction of asphaltic concrete.

The discussions given in the following paragraphs are based on and pertaining to only densely graded, gravel, sand and mineral filler mixtures. Different aggregates and gradations may and probably will require different conditions.

Temperature-Viscosity Relationship

Paving asphalts being Thermoplastic materials are rendered fluid by heating. The degree of fluidity achieved is a factor of temperature, grade, and method of production of the asphalt and the crude from which it is produced. The degree of fluidity of asphalts generally are measured by use of the Saybolt Viscosimeter in terms of time - in seconds - it takes 60 ml. of a given asphalt at a given temperature to flow through a known orifice. This value is commonly referred to as the Saybolt-Furol Viscosity in seconds (ASTM Designation: E 102-54T). Throughout this paper the term viscosity will be used synonimously with Saybolt-Furol Viscosity in seconds (SSF). Some of the values given will be beyond the range of Saybolt Viscosimeter in which case these were determined by the Sliding Plate Microviscometer and converted to seconds.[1] Regardless of the method used, however, the viscosity of asphalts is a fundamental property.

In order to have a better understanding of viscosity-temperature relationship, it is necessary, first, to briefly show the effects of temperature on viscosity for different grades of asphalt. The curves, given in Figure 1, define such a relationship for three grades of asphalt 62, 87 and 137 penetration (tested at 77 F). All three are from the same source. A wide difference is noted between viscosities of different grades of asphalt at lower temperatures. This difference diminishes at elevated temperatures. For instance, at 325 F viscosity for 62

[1] $$\text{Viscosity - SSF} = \frac{\text{Viscosity in Poises} \times 100}{2.08 \times \text{Specific Gravity}}$$

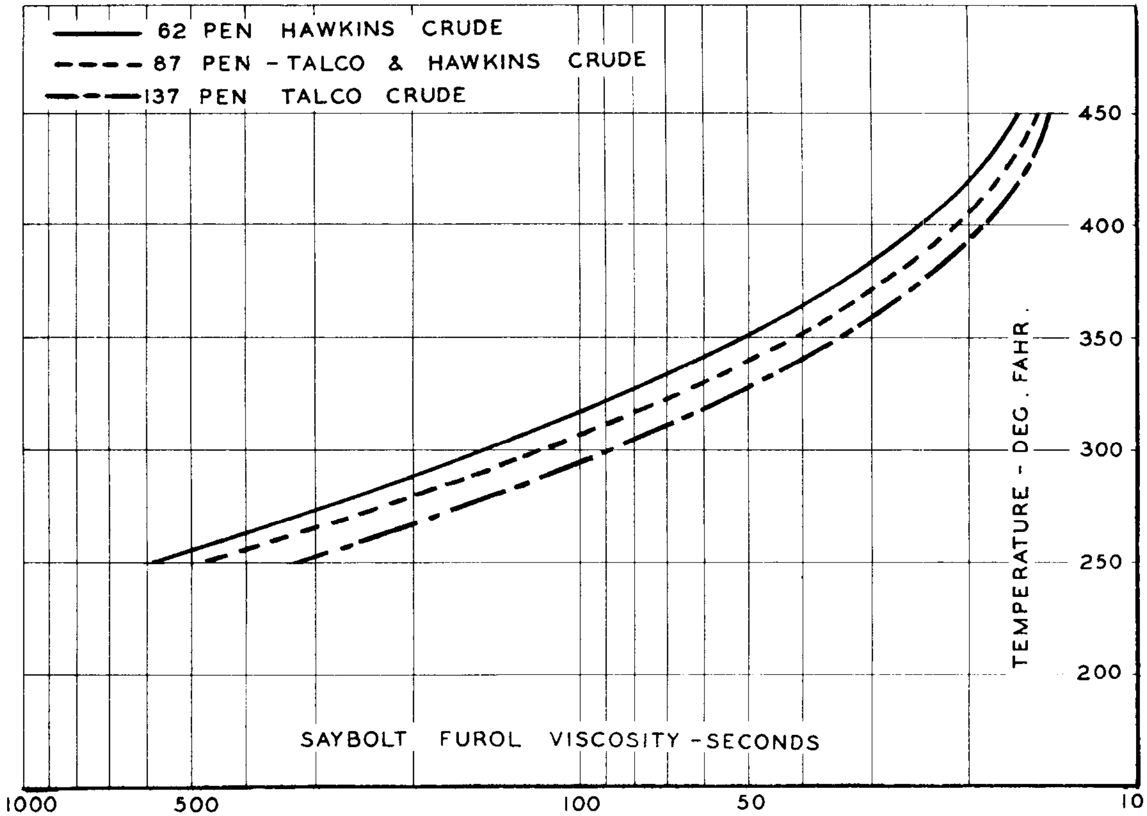

Figure 1 - Viscosity-Temperature Relationship of Three Different Grades of Asphalt Cement.

pentration asphalt is 85 seconds Saybolt-Furol (SSF), for 87 penetration it is 68 SSF and for 137 penetration asphalt it is 53 SSF. Thus, for a given source the viscosity decreases as the penetration increases. This statement, however, is limited to only a given source and base crude and should not lead to the misconception that, regardless of source and crude, all asphalts of a given grade have similar viscosity-temperature relationships. Although asphalts of a certain grade but of different sources sometimes show identical viscosities, occasionally, they have shown entirely different values.[2] To illustrate this point Figure 2 was prepared. It shows a band with the upper and lower limits of viscosity-temperature relationships for six asphalts, of 60-70 penetration grade. The lower curve represents the viscosity characteristics of another 60-70 penetration grade asphalt. As will be noted it is entirely removed from the upper band. For example, the six asphalts represented show viscosities ranging from 600 to 700 SSF at 250 F whereas the lower curve has a viscosity of 350 SSF at this same temperature. Meaning that the latter asphalt when heated to 250 F is more fluid than the former six grades. To illustrate the point better, this asphalt, even though of the same penetration grade, will be at the same fluid state at only 233 F.

Mixing Viscosity

Mixing temperature for asphaltic concrete mixtures, using paving grade asphalts, has

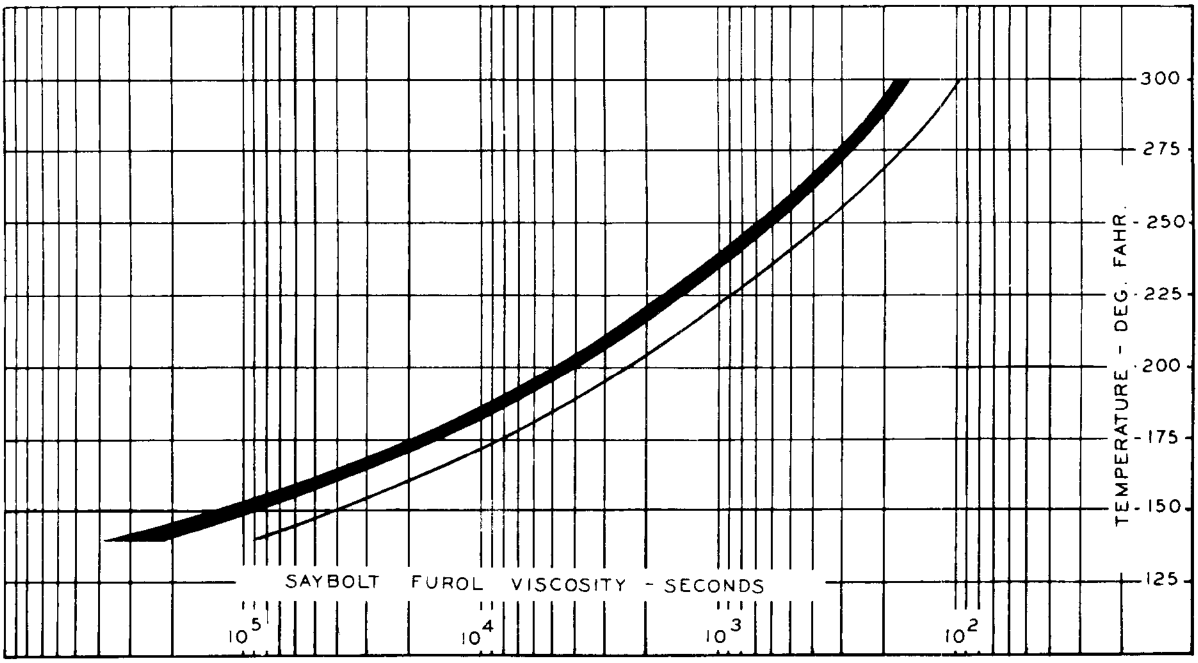

Figure 2 - Viscosity-Temperature Relationship of Several 60-70 Penetration Grade Asphalts

certainly been one of the most controversial subjects as well as the most frustrating to the specifications writer. For example, in 1954 it was reported that the temperature requirements for mixing used by 44 agencies in United States ranged from 200 to 375 F.[3] This disagreement, we believe, is caused by the varying viscous properties or the viscosity-temperature relationships of the asphalts used.

Let us first discuss the mixing temperatures required for three grades of asphalt from the same source. Figure 3 shows the Marshall Stability values obtained with mixtures prepared using the same aggregate and mixed at different temperatures as indicated. The three asphalts used are those shown in Figure 1.

Each curve has a peak at a different temperature. For example, curve for 62 penetration asphalt has its peak at 325 F, 87 penetration at 315 F and 137 at 300 F. In other words, as the asphalt gets softer, the temperature of the peak decreases. Assuming that each peak is the optimum mixing temperature for the corresponding asphalt, why are they at different temperatures? Additional study of Figures 1 and 3 will reveal that, even though the optimum mixing temperature is different for each one of these asphalts, the corresponding viscosities of all are 85 seconds.

Figure 4 shows the Marshall stability-mixing viscosity relationship. The general trend of all three curves is the same. Curve for 62 penetration asphalt shows a low stability value of 1030 lb. at 580 SSF, at a corresponding temperature of 250 F. This value gradually increases with decreasing viscosity increasing temperature reaching a peak value of 1230 lb. at a viscosity of 85 SSF (325 F). From there on stability remains constant for a

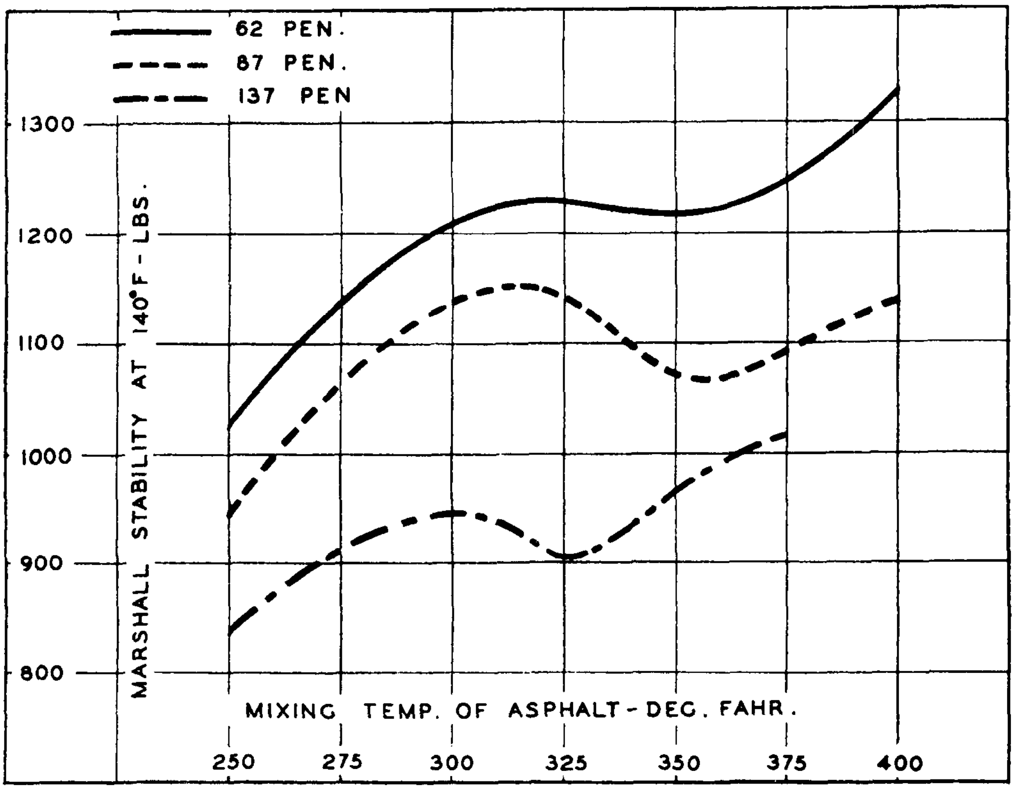

Figure 3 - Relationship of Mixing Temperatures of Asphalt-Marshall Stability at 140° F of Laboratory Prepared Specimens

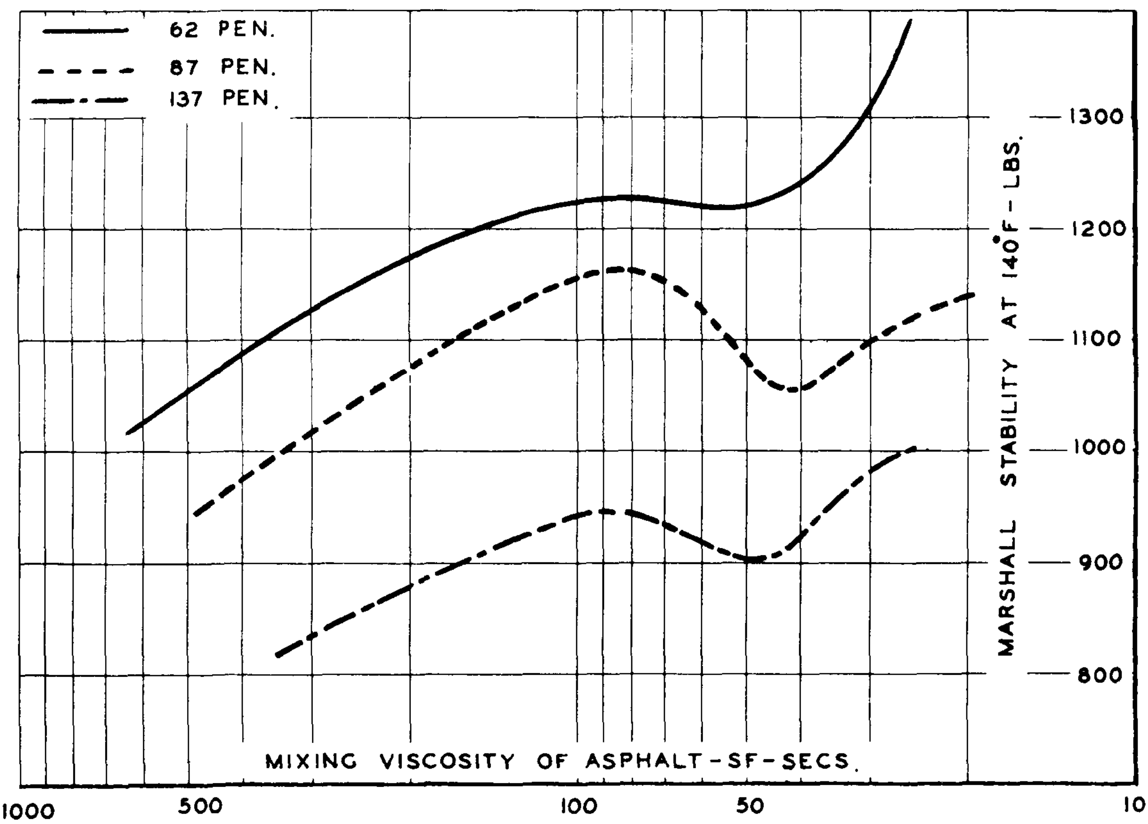

Figure 4 - Relationship of Mixing Viscosity-Marshall Stability at 140° F at Laboratory Prepared Specimens

30 second range and, then again, starts to ascend to a maximum value of 1420 lbs. at 25 seconds (400 F).

The curve for 87 penetration asphalt also defines the same relationship reaching a peak value of 1160 lbs. at 85 seconds and from this point instead of remaining constant, as in the first case, drops to 1060 lbs. at 45 seconds and again suddenly starts increasing to attain a value of 1135 lbs. at 20 seconds.

The last curve - 137 penetration asphalt - again shows an identical relationship between mixing viscosity and Marshall stability with a peak at 85 SSF, a drop from the peak at 45 SSF. Thus we see that in all three curves, the peak and inversion point occur at practically the same viscosity.

The above relationship shows that intimate coating, correct film thickness and a uniform dispersion are not achieved until aggregate and asphalt temperatures are high enough to permit droplets of bitumen to envelope particles of aggregate upon contact. In order to rapidly wet the aggregate, bitumen must flow freely or be in a state of low viscosity. At high viscosity values, with corresponding low temperatures, this intimate coating is not achieved, until such a point where fluidity reaches an ideal state to coat the aggregate particles thoroughly and properly, to insure good bondage. Further rise in temperature makes the asphalt extremely fluid and attain such a state that, instead of coating the particles, to obtain a uniform thickness to insure proper bondage, it merely lubricates the particles causing excessive movement under dynamic impact of hammer, thereby giving mal-orientation. This results in a drop in stability from the peak. Further rise in stability from there on could very well be attributed to the hardening or oxidizing of asphalt which result in a change in consistency.

Movement of the particles due to a low viscosity during compaction is not the only factor that affects stability. Even though samples are compacted at a constant temperature but mixed at different temperatures or viscosities the results will be affected. Figure 5 shows effects of mixing viscosity on stability when compaction temperature is kept constant at 275 F. for an 85-100 penetration grade asphalt and the peak for stability curve is again at a viscosity of 85 seconds. However, the extent of the effects of variations in mixing viscosities are not as great as both the mixing and compaction viscosities, shown in Figure 5. Results show that regardless of the compaction temperature, Marshall stability is greatly affected by mixing viscosity. Likewise, compaction temperatures affect stability if the mixing temperature is kept constant. Effects of mixing viscosity on percent of theoretical gravity is also shown in the same figure and again defines the same relationship as stability-viscosity.

Discussions given so far were limited to only laboratory mixed samples. In an effort to confirm the results obtained in the laboratory, with those mixed at a hot mix plant under actual construction procedures, another study was made. In this case, hot mix

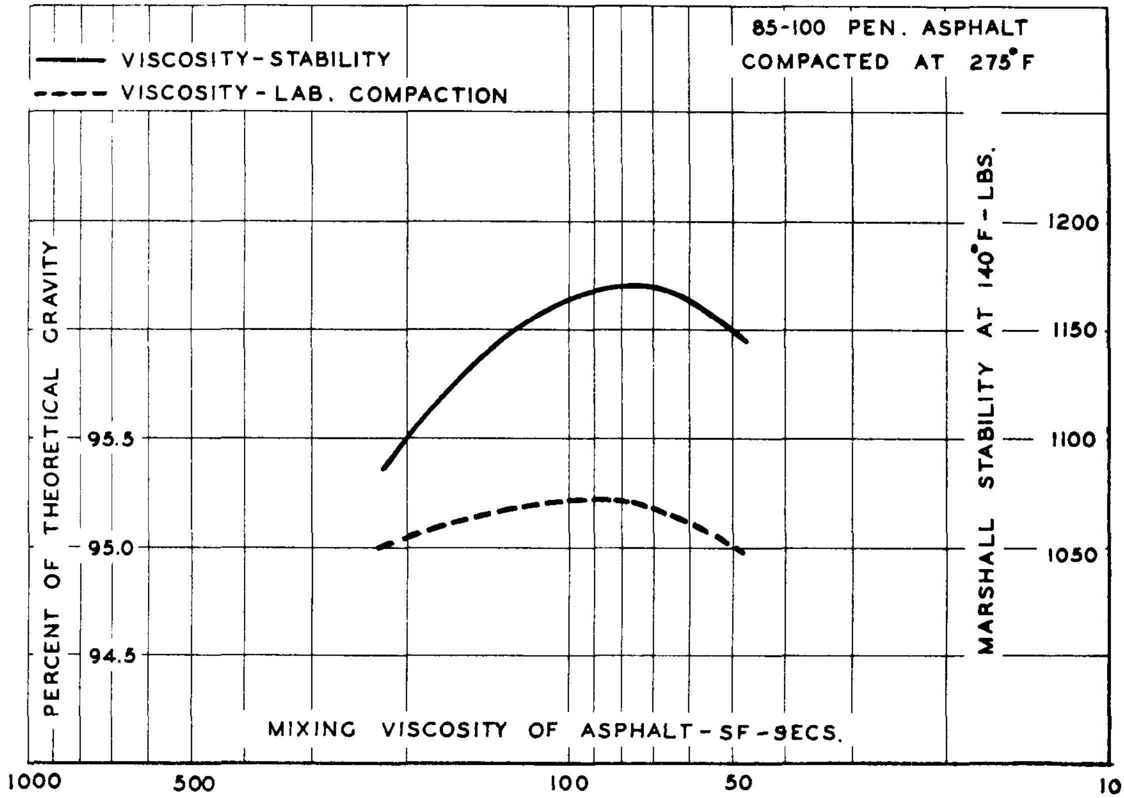

Figure 5 - Relationship of Mixing Viscosity-Marshall Stability at 140° F for Specimens Compacted at 275° F

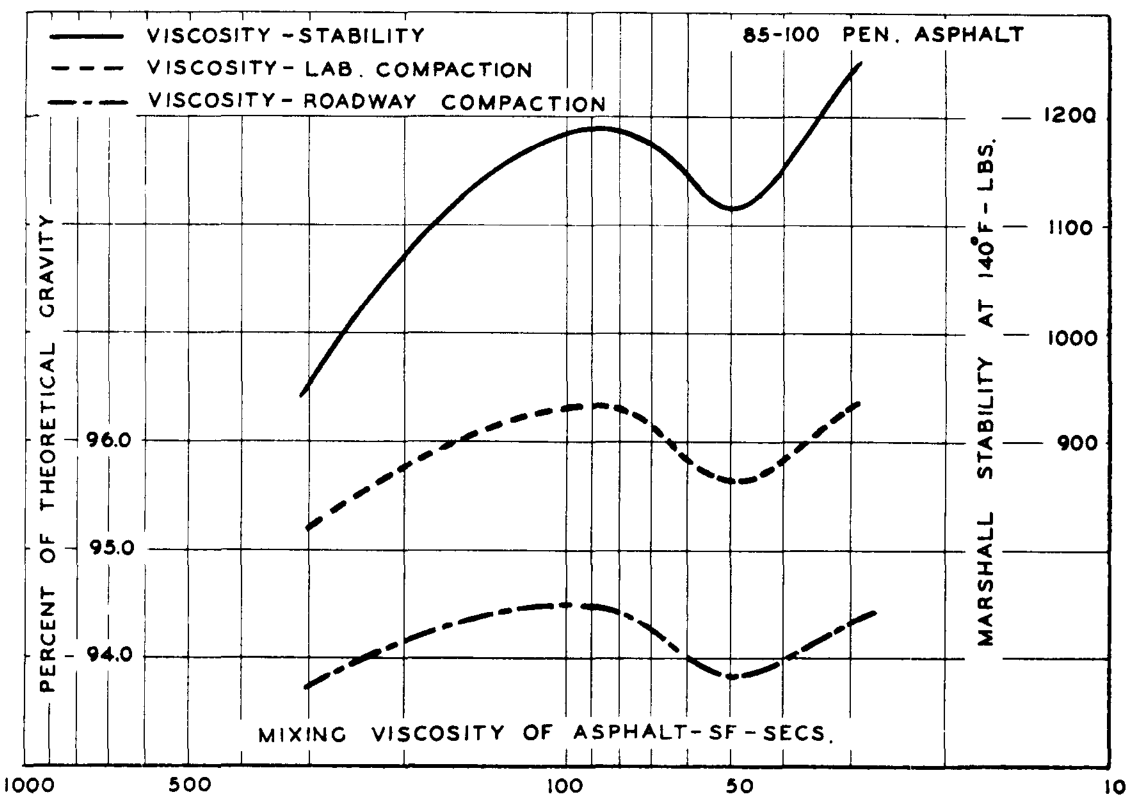

Figure 6 - Relationship of Mixing Viscosity vs.: Stability, Percent of Theoretical Gravity of Briquets and Percent of Theoretical Gravity (Roadway Density) Pavement after Rolling under Controlled Compactive Effort.

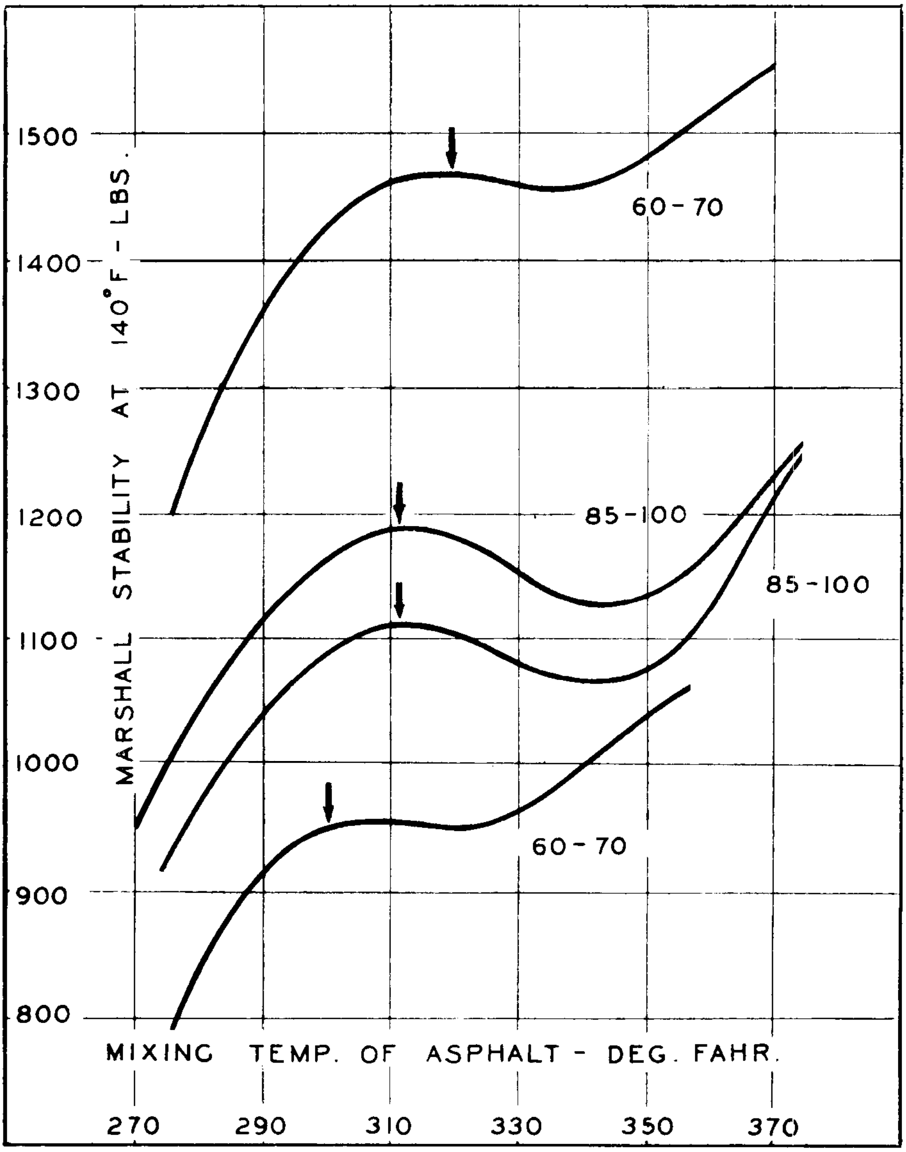

Figure 7 - Mixing Temperature - Marshall Stability at 140 F of Plant Mixed Samples

samples were taken from trucks at regular intervals, compacted and tested. The relationship obtained are shown in Figure 6. These are mixing viscosity versus: stability, percent of theoretical gravity of briquets and percent of theoretical gravity of the same mixtures in the pavement after rolling (roadway density) under a controlled compactive effort. It will be interesting to note that in this case, too, the peak and the trough occur at 85 SSF and 45 SSF, respectively, for all three relationships.

Reasonable variations in gradation and filler and asphalt contents do not affect the optimum mixing viscosity of mixtures produced at hot mix plants. Figure 7 shows the mixing temperature-stability relationships of four different mixtures produced for four different projects. The aggregate gradations and sources, filler and asphalt contents are different in each case. It will be noted that peaks are at different temperatures.

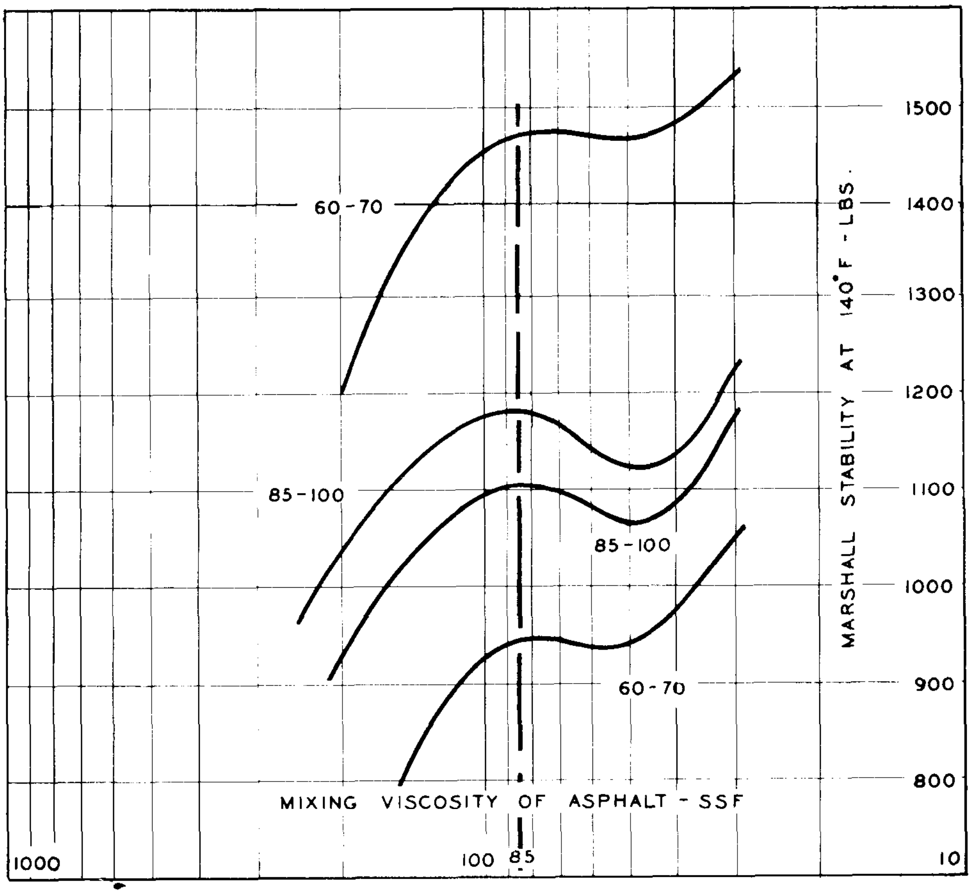

Figure 8 - Mixing Viscosity - Marshall Stability at 140 F of Plant Mixed Samples Given in Figure 7

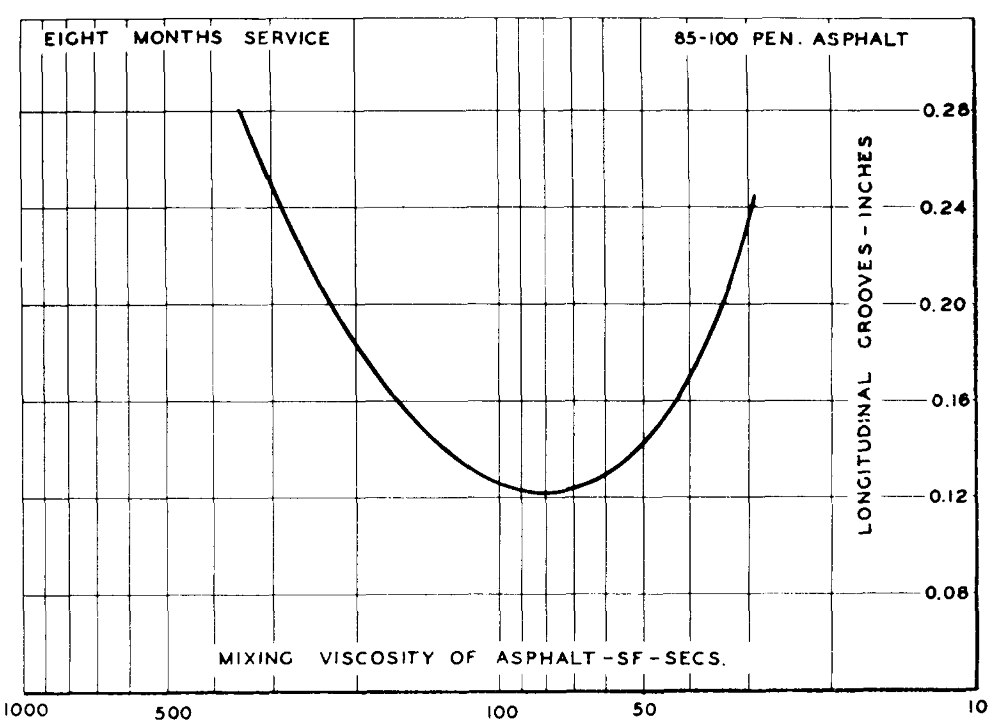

Figure 9 - Mixing Viscosity-Rutting Relationship

When the viscosity-stability relationship is plotted for each of these mixtures, however, all the peaks or the optimum mixing viscosities are the same, namely, 85 SSF (Figure 8). Another interesting feature of this figure is that, excessive variations from the optimum viscosity show anywhere from 250 to 330 lbs. reduction in stability for the same type of mix. Which, once again emphasizes the importance of viscosity control and the use of proper fluidity in production of asphaltic concrete.

Close control of the resistance of pavement to plastic deformation at maximum road temperatures - i.e., tendency to rut, shove, or otherwise displace under traffic - is essential for satisfactory performance. Whether any of the aforementioned properties (rutting, shoving, etc.) are appreciably affected under traffic by mixing viscosity remains to be studied in these series of investigations. However, data collected so far from one of our recent research projects, to seek the relationship between rutting and mixing viscosity are given in Figure 9. Sections, laid with mixture, mixed at a viscosity of 360 SSF show a pronounced rutting of 0.28 in. in eight months. This rutting diminishes for sections representing a lower mixing viscosity. The least affected was section mixed at 85 SSF. Rutting, again, increased as the viscosity became considerably lower. Studies on two other projects are in progress on this aspect and will be reported upon completion. Mixing and compaction viscosities, in laboratory design will play just as important a role as it does in construction. Strict temperature-viscosity requirements should be used if comprehensive results are desired. Furthermore, if optimum mixing viscosity is not used during design, a thicker film of asphalt will be obtained resulting in a high optimum design asphalt content or visa-versa. Similarly, if an 85-100 penetration asphalt and a 60-70 grade are heated to the same temperature for mixing, in designing a mixture, the harder asphalt will show a higher optimum asphalt content with the same aggregate.

Rolling Viscosity

Most highway engineers sometime or other have probably been faced with a "soft" or a "tender" mix or one that did not support the roller at normal rolling temperatures. It is only logical to assume that aggregate characteristics play an important role in softness of a mix. Likewise, the consistency of the binder at the time of rolling will have considerable influence on the supporting power or its resistance to compaction or displacement as the case may be.

The indications of the data obtained so far are that for reasonably close aggregate characteristics asphalt and filler contents, the viscosity of the binder during compaction controls density to a great extent, and the proper rolling viscosity stays same. In support of this statement Figure 10 was prepared. Data given represents the effects of temperature on roadway density of two different projects. It will be noted that in each case the highest density was obtained at different temperatures. Curve A represents a low viscosity asphalt, where curve B shows higher viscosities. Therefore,

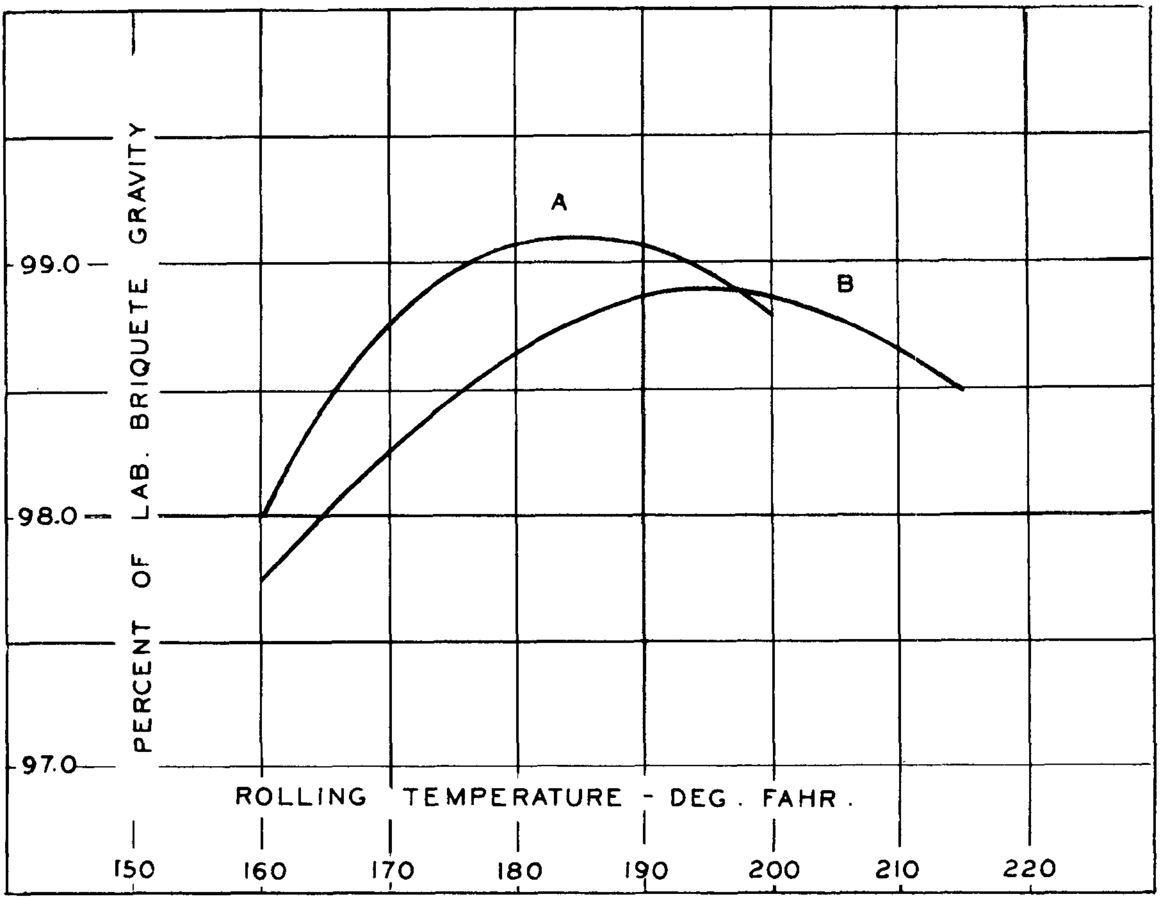

Figure 10 -Rolling Temperature - Percent Compaction Relationship of Two Different Mixes Using Two 60-70 Penetration Asphalts from Different Sources. Rolling temperature is for Pneumatic Rolling. 15 passes, 55 psi tire pressure and 2000 lb. on each wheel

the peak of Curve A is at a lower temperature than B. When these same results are plotted versus the respective viscosities of these asphalts at the temperature of rolling (Figure 11) both peaks are at the same viscosity. The temperatures given are for pneumatic rolling (15 passes, 2000 lb/wheel and 55 psi). Nevertheless, three-wheel rolling temperatures show the same relationship.

In other words, low viscosity asphalts will require low rolling temperatures when used with criterion designed for high viscosity asphalts. These asphalts will also show higher densities for the same compactive effort, meaning that they are easier to densify when the same asphalt content is used. Furthermore, they will be "tender" longer and will require a longer cooling period before final rolling can be done and the road opened to traffic.

Performance Versus Viscosity

Will the viscosity of asphalts at service temperatures affect the service behavior of pavements?

We do know that viscosity is a measure of resistance to shearing under a given load. When the Sliding Plate Microviscometer is used, the viscosity value is determined directly from the shear stress. The film thickness is very similar to that obtained in the field under actual construction procedures. Soft asphalts, regardless of the penetration grade, show very low resistance to shear. Thereby, their viscosities are low. Hence, it is safe to assume that they will behave in the same manner in a pavement and tend to displace easier and sooner, thereby be more susceptible to rutting, shoving and displacement. To illustrate this point let us refer to Figure 12 temperature-viscosity relationship of three asphalts. Asphalts R and S show penetrations of 62 and 66 respectively, where asphalt T is 137 penetration. It will be noted that curve R shows much higher viscosities than S. And S is very similar to T. Marshall briquets made using asphalts R and S and tested at 140 F showed stabilities of 1430 lb. and 1280 lb. respectively. It will be noted in Figure 12 that R has a viscosity of 2.9 x 10^5 seconds and S 0.9 x 10^5 seconds at 140 F. It will further be noted that saphalt S will have a viscosity of 2.9 x 10^5 seconds at 128 F. Marshall specimens made with Asphalt S tested at this temperature showed a stability value of 1490 lb. as compared to 1430 lb. from asphalt R.

It seems obvious, from the preceding, that, for a given aggregate and asphalt content, the resistance of a mixture to displacement is related to the viscosity of the asphalt at

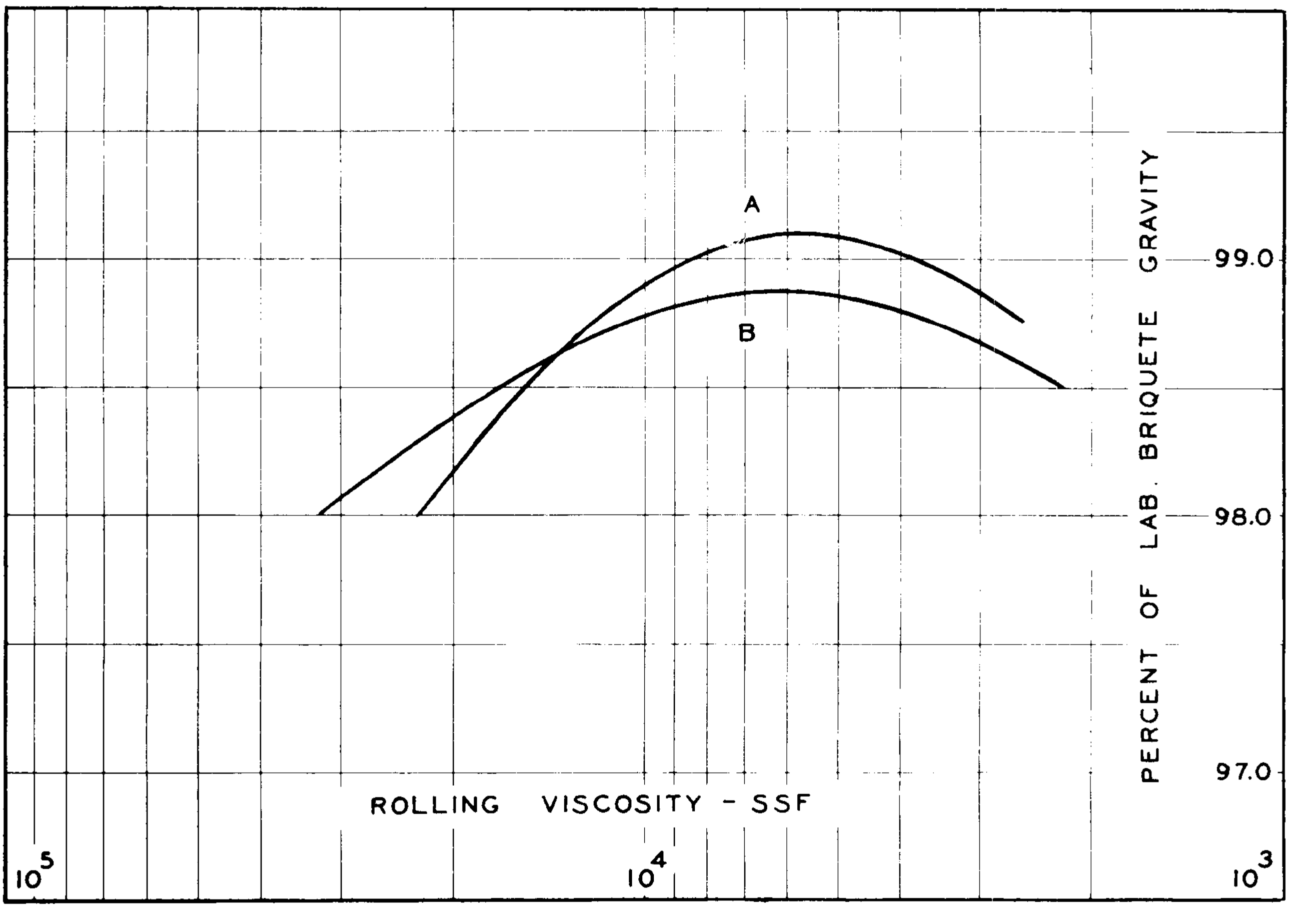

Figure 11 - Rolling Viscosity - Percent Compaction Relationship - Same as Figure 10

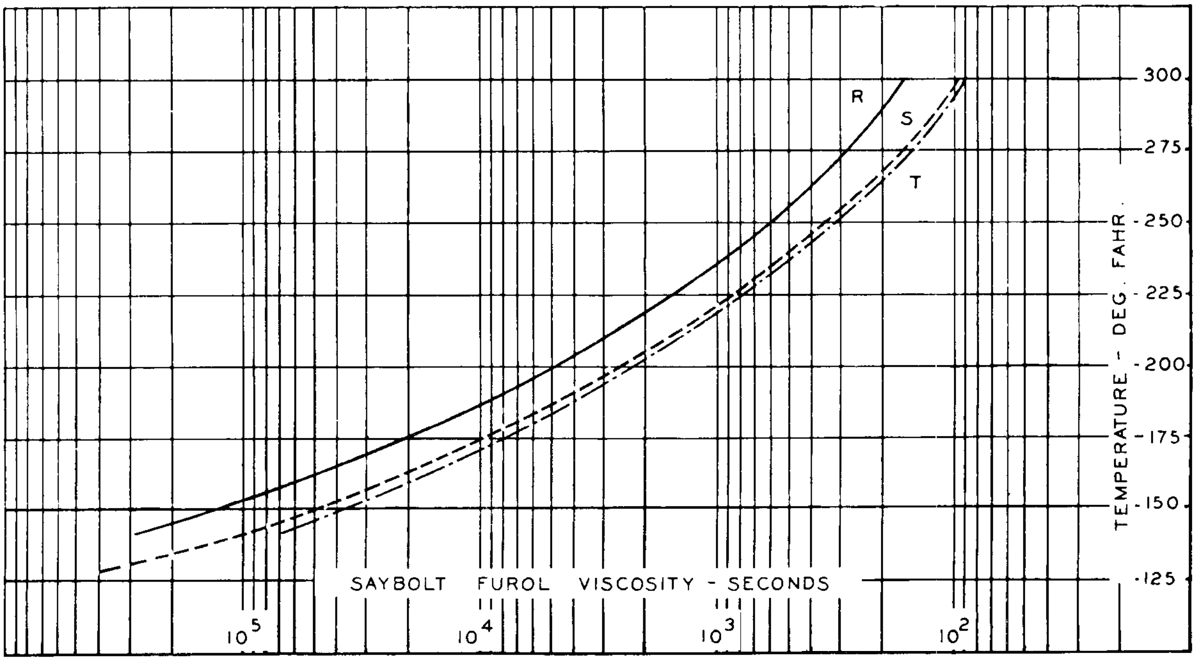

Figure 12 - Viscosity - Temperature of Three Asphalts - R) 62 Penetration, S) 66 Penetration and T) 137 Penetration

service temperatures. Likewise, asphalt S, being so close to a 137 penetration asphalt, as far as viscosity is concerned, should behave like a 120-150 penetration grade. Since, it has been established that the satisfactory pavement coverage life under heavy loads [4] is particularly affected by the hardness of asphalt, particular emphasis should be given to viscosity at service temperatures when grade is being specified. We believe, control of consistency of paving asphalts by viscosity at 140 F would be more meaningful than specifying penetration. This is particularly true in localities where good aggregates are not available and so much depends on the binding ability of asphalt.

Conclusion

In conclusion it can be stated that viscosity at each stage of construction is a fundamental property of asphalt cements. For given aggregate characteristics it considerably affects:

1. Proper film thickness of the asphalt and adequate coating of the aggregate.
2. The rolling temperature and compactive effort needed.
3. Performance of pavements during service.

There are possible counter measures for deficiencies in viscosity. Nevertheless, the feasibility of using such remedies will depend on several factors.

The stability of a mixture can be improved by a reduction in asphalt content and an increase in compactive effort. This certainly would improve the resistance of the pavement to displacement when low viscosity asphalts are used. However, it can only be done if the climatic conditions or the traffic volume of the road permit such a change. For

REFERENCES

1. Viscosity Effects in the Marshall Stability Tests, D. F. Fink and J. A. Lettier, Proceedings, Association of Asphalt Paving Technologists, Volume 20, 1951, p. 248.

2. Properties of Highway Asphalt - Part I, J. Y. Welborn and W. J. Halstead, Public Roads, Volume 30, No. 9, p. 197.

3. Summary of State Practices in the Use of Bituminous Concrete Mixtures, W. E. Chastain, Sixth Highway Engineering Institute, 1954.

4. Report of Bituminous Pavement Conference, October 9, 1957, Waterways Experiment Station, Vicksburg, Mississippi.

5. The Effects of Viscosity of Asphalt Cement at the Temperature of Mixing on the Properties of Bituminous Mixtures, J. M. Griffith, Highway Research Board, 1959.

6. Application of Marshall Method in Hot Mix Design, H. L. Lehmann and Verdi Adam, Sixty-Second Annual Meeting, ASTM, 1959.

7. Asphaltic Concrete Manual, Louisiana Department of Highways, 1959.