2571

SOME FACTS AND OPINIONS ABOUT SPECIFICATIONS FOR ASPHALT CEMENT

by

Woodrow J. Halstead
Research Consultant

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

April 1980

VHTRC 80-R43

2572

BITUMINOUS RESEARCH ADVISORY COMMITTEE

R. L. ALWOOD, Chairman, District Materials Engineer, VDH&T

A. D. BARNHART, District Materials Engineer, VDH&T

P. F. CECCHINI, District Engineer, VDH&T

J. L. CORLEY, Assistant District Engineer — Construction, VDH&T

W. R. DAVIDSON, Assistant Maintenance Engineer, VDH&T

W. A. DENNISON, District Materials Engineer, VDH&T

C. E. ECHOLS, Asst. Prof. of Civil Engineering, U. Va.

R. V. FIELDING, Materials Engineer, VDH&T

C. S. HUGHES III, Highway Research Senior Scientist, VH&TRC

A. B. JOHNSON, Assistant Construction Engineer, VDH&T

J. T. LOVE, Materials Engineer, Materials Division, VDH&T

H. E. MARSHALL, District Engineer, FHWA

C. G. MCALLISTER, Chief Chemist, Materials Division, VDH&T

R. S. THOMAS, Bituminous Engineer — Maintenance Div., VDH&T

R. D. WALKER, Chairman, Dept. of Civil Engineering, VPI & SU

PREFACE

This paper was presented in part at the conference on "Asphalt: Its Effect on Pavement Performance", which was jointly sponsored by The Asphalt Institute, the National Asphalt Pavement Association, and the Federal Highway Administration. The conference was held at College Park, Maryland, on March 27, 1980.

The paper is a synthesis of information drawn from published reports as well as unpublished memoranda and committee reports available to the author because of his earlier involvement in the development of specifications for asphalt in the American Association of Highway and Transportation Officials (AASHTO), American Society of Testing Materials (ASTM), and the Federal Highway Administration (FHWA). It is recognized that there are some differences of opinion among asphalt technologists on some of the points discussed. Accordingly, the viewpoints expressed are those of the author, but it is believed that such viewpoints are those that prevailed in the adoption of the various requirements of asphalt specifications as represented by the AASHTO and ASTM.

This documentation should prove useful to persons interested in broadening their understanding of the complexities of asphalt cements, and it provides references to previous research that might not be readily available to persons just beginning the study of asphalt technology.

2574

SOME FACTS AND OPINIONS ABOUT SPECIFICATIONS FOR ASPHALT CEMENT

by

Woodrow J. Halstead
Research Consultant

INTRODUCTION

Petroleum asphalt has been used in the construction of highways since about 1900. From that time to the present, hundreds of articles have been written concerning its properties and how such properties affect the performance of pavements in which it is used. Considerable attention has also been given to how the desirable properties can be assured by specifications. Therefore, it would seem that by now all the answers should have been determined. Unfortunately, asphalts are a lot like people; they can be characterized and cataloged into types and classes, but their performance under a given set of circumstances can't always be predicted.

Research studies involving the properties of asphalt sometime tend to stress the differences between materials and overlook the fact that despite these differences, asphalts have an admirable track record. Far more asphalt pavements have performed as expected than have undergone early or unexpected failures. This report reviews some of the facts concerning asphalts and some of the data supporting present specifications. Some of the controversial problems and differences of opinion that still exist are also discussed. These differences come about because different persons tend to look at different aspects of the problems much the same as the three blind men describing what an elephant looks like. Each description is valid for that part of the problem being explored, but often the total picture is lost. An effort has been made in this discussion to back off and look at the entire elephant.

GENERAL PROPERTIES OF ASPHALT

What is known for certain about asphalt cements? The laborer or technician working at the asphalt plant may know only that in the tank it is a hot, thick liquid and that it burns like h--- if some spatters on him. If a can of the stuff is left to cool inside the laboratory, it becomes a semisolid that can be pushed in with the finger and may or may not stick to it. If the can is put outside in cold weather, the asphalt becomes hard and brittle and probably can be dented only slightly with the fingernail. In scientific terms, such behavior is defined as that of a complex material. At high temperatures the asphalt behaves as a true viscous liquid (Newtonian flow). At intermediate temperatures, it behaves as a viscoelastic material and the behavior is dependent on both the temperature and the duration of loading. At low temperatures and short times of loading, the asphalt behaves as an elastic solid.

From a chemical standpoint, it is known that asphalt is made up of a large number of hydrocarbon molecules of different degrees of complexity and with some additional chemical elements, particularly oxygen, nitrogen, and sulfur. The amounts of the various compounds vary depending on the source and method of refining of the petroleum. Despite considerable attempts to analyze and characterize asphalts by their chemical composition, there remains considerable uncertainty in this area. Everyone agrees that asphalts for building highways cannot be specified on the basis of their chemical composition. Thus, dependence is placed on tests that measure certain physical characteristics of the material.

Krom and Dorman list the three main characteristics of asphalts that must be considered in relation to its quality as

1) mechanical properties, i.e. properties governing behavior under stress;

2) adhesion; and

3) durability, i.e. changes in properties during storage, application, and service.(1)

For specification purposes, mechanical properties are generally controlled by measurements of consistency (penetration or viscosity). Adhesion is not controlled directly because it depends greatly on asphalt-aggregate interactions. However, ductility may be indirectly related to adhesion. Durability is controlled by measuring the hardening effects of heat and air at high temperatures on the asphalt, which are known to be related to the hardening during mixing and, to some extent, the rapidity of hardening in service.

These parameters will vary from asphalt to asphalt. While a grade of asphalt can be arbitrarily defined as covering a specified range of consistency at a specific temperature, for asphalts from different sources, consistency often changes to a different extent with changes in temperature — that is, different materials have different viscosity-temperature susceptibilities. They also react differently to various times of loading at service temperatures, particularly the low winter temperatures. The latter phenomenon is termed shear susceptibility.

It is also known that adequate performance can be attained with materials that vary widely in these characteristics, provided the pavement mixture is properly designed and the pavement is properly constructed. The problem is how to write a specification that will not be unduly restrictive but will exclude unsuitable materials and guard against widely different behaviors for materials meeting the same specification.

ASPHALT SPECIFICATION REQUIREMENTS

As a basis for this discussion, a review was made of how problems such as those cited above are addressed in the present ASTM and AASHTO specifications. Both organizations have a specification based on grading by viscosity at 140°F and a specification based on penetration at 77°F. These are usually referred to, respectively, as "viscosity grading" and "penetration grading". Within each type the grade designations are the same for both organizations but there are some minor differences in requirements.

Asphalt Grading Systems

At the beginning of highway construction with petroleum asphalt, it was recognized that asphalts with different degrees of hardness or different consistencies were needed for different purposes and different climates. Consistency can be measured in a number of ways. In the very early days of highway construction this was done by chewing a piece of asphalt. If it crumbled, it was the hard grade; if it chewed like gum, it was the medium grade; and if it stuck to the teeth, it was the soft grade.

The penetration test was invented around 1888 and became an ASTM standard in 1911. From that time until 1970 it was the standard means of designating the grade of asphalt. However, interest in developing a more fundamental measure of consistency for asphalts dates back to the early 1920's. In 1923 ASTM held its first symposium on the subject. The big push for developing asphalt specifications based on viscosity resulted from a recommendation of the Highway Research Board's Ad Hoc Committee on Research Problems of Mutual Concern to Users and Producers of Asphalt. This committee's recommendation, issued in 1961 after several years of discussion, was that test methods be developed to measure consistency of all asphaltic materials in fundamental units over the entire temperature range of interest for handling, construction, and asphalt extracted from pavements in service. In addition, the test methods would be adequate for use in specifications.

The first effort in this program was the establishment of a method for determining the kinematic viscosity of all grades of cutback asphalts at 140°F (60°C), and the development of the specifications based on kinematic viscosity. This effort began in 1962 and within a few years a test method had been standardized and specifications based on kinematic viscosity had been accepted by all states. However, the effort to establish a system for asphalt cements based on viscosity grading was drawn out over a long period of time. The Asphalt Institute issued its "Study Specifications for Asphalt Cements Based on Absolute Viscosity at 140°F" in 1963, and for a period of at least 10 years, numerous discussions and workshops were held on the relative merits of penetration grading vs. viscosity grading, what the viscosity limits for the grades should be, and what temperatures should be used for control points. The first American Association of State Highway and Transportation Officials' specification, which was adopted in 1970, had a single set of limits representing what the AASHTO subcommittee considered a reasonable compromise of several viewpoints but which proved to be unacceptable to many. This difference in opinion resulted in the adoption, in 1971, of the three alternative sets of limits now found in both AASHTO M226 and ASTM D3381. The AASHTO assumed that after a shakedown period the specification based on penetration grading would be withdrawn but, because some organizations still prefer penetration grading, it remains as an optional approach.

The Rationale for Viscosity Grading

The next question to consider is, What is gained by using viscosity grading in lieu of penetration grading?

The first, and noncontroversial, fact is that the use of viscosity provides a measure of consistency based on fundamental units of force, time, and distance. Consequently, it does not limit one to obtaining results with a single instrument. Although it is necessary to use different instruments to cover the entire temperature range of interest, the results are still comparable. The penetration test has often been criticized because it is empirical, but it does a good job of measuring consistency within the range at which it can be employed. The real problem is its greatly limited range. Penetration results less than 10 are not sensitive enough to be useful, and around 300 penetration the material becomes too soft for proper measurements. The change occurs for highway asphalts from about 50°F to 95°F — a very small portion of the total temperature range of interest.

The Penetration-Viscosity Relationship

There are differences of opinion concerning the correlation between penetration and viscosity at the same temperature. Some authors are concerned about measured differences in viscosity for equal penetration that are relatively large, while others have established an equation for the best line through a plot of log viscosity vs. log penetration based on the method of least squares. Correlation factors between calculated viscosities and measured penetration then range from about .95 to .98 — which is considered a good correlation. In general terms, this indicates that while there are substantial differences in viscosities for equal penetrations for a few asphalts, most of the time a calculated viscosity based on a measured penetration will be close enough for practical purposes.

Figures 1 and 2 illustrate data obtained in different studies. Figure 1 is from a study of Ontario asphalts by Fromm and Phang.[2] The solid line in this figure is the linear regression line and the dotted lines are the 95% confidence limits. As can be seen, essentially all the values fall within these limits. The equation for the line is

$$\log V = 9.889 - 2.00 \log P,$$

where

V = Viscosity in poises, and

P = Penetration in 0.1 mm at 77°F.

Figure 2 is from a study by Griffith and Puzinauskas in 1962.[3] These authors stress the wide differences in viscosity for the same penetration grade, noting that the extremes outlined in the figure represent differences in viscosity ranging from 0.5 to 1.6 Mega poises for the range in penetration between 85 and 100. As can be seen the two sets of data have about the same spread. Consequently, it is a matter of viewpoint as to whether the correlation is considered good or bad.

Others have reported relationships between viscosity and penetration at 77°F. When these relationships are all converted to the logarithmic form they are as follows:

log V (poises) 10.266 - 2.198 log P (Carne and Laurent)[4]

log V (poises) 9.86 - 1.89 log P (Welborn et al.)[5]

log V (poises) 9.710 - 1.93 log P (Saal)[6]

An unpublished relationship developed from Bureau of Public Roads (BPR) data at various temperatures and for a large number of asphalt sources gave the equation

$$\log V \text{ (poises)} = 10.14 - 2.11 \log P.$$

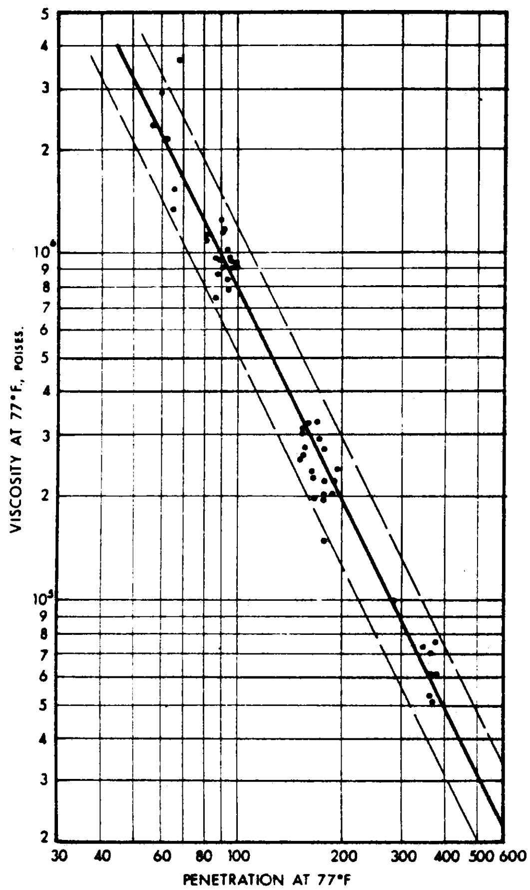

Figure 1. Viscosity at 77°F versus penetration at 77°F for Ontario asphalt cements used in 1969 and 1970. (From reference 2.)

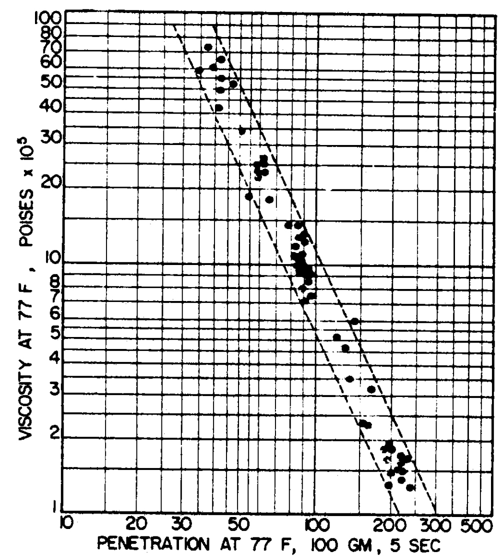

Figure 2. Correlation between viscosity at 77°F and penetration at 77°F for different asphalt cements. (From reference 3.)

Although these equations do not agree precisely, the important point is that they show that viscosity varies about as the reciprocal of penetration squared — so that a certain percentage change in viscosity does not result in the same percentage change in penetration. What appears to be an unusually large change in viscosity appears much smaller when expressed as a penetration change.

A good approximate relationship is defined as:

$$\log V \text{ (poises)} = 10.0 - 2.0 \log P.$$

On this basis the equivalencies of viscosity and penetration at several points are defined in Table 1. A good rule of thumb is that if viscosity increases 10-fold the penetration has been reduced to one-third of its original value.

Another point to remember is illustrated in Table 2. That is, the percentage change in viscosity with a given number of degrees change in temperature varies substantially. Thus, as shown, it takes only about a 13° to 14° change in temperature at low temperatures to produce a 10-fold change in viscosity, but at the mixing temperature it takes a 70° to 90° change in temperature to change viscosity 10-fold.

Table 1

Approximately Equivalent Penetrations and Viscosities

Penetration[a]	Viscosity Poises
300 (250)	100,000
100 (92)	1,000,000
30 (31)	10,000,000
10 (10)	100,000,000

Rule of thumb: Applicable in 45°-90°F range 10-fold increase in viscosity reduces penetration to 1/3 of its original value.

(a) Values in parentheses are from a curve of plotted data in reference 8.

Table 2

Approximate Temperature Changes Required to Change Viscosity by a Factor of 10 at Various Temperature Ranges

Temperature Range, F°	Viscosity-Temperature Susceptibility	
	High	Low
Freezing (30-35)	13	14
Normal (50-80)	15	20
Hot Summer (130-150)	30	35
Compaction (175-200)	38	50
Mixing (280-320)	70	90

Significance of Temperature Change for Asphalt Grading

The second and more important change in going from penetration grading to viscosity grading is a change in the temperature at which the asphalt grade is determined. For penetration grading, the consistency at 77°F is used. For viscosity grading, the consistency at 140°F is used. As previously indicated, problems arise because of differences in viscosity-temperature susceptibilities of asphalts from different sources. Different asphalts of the same penetration grade will not always have the same equivalent grade classifications under the viscosity grading system.

Data reported by the BPR in 1963 provide support for the viscosity at 140°F as the grade control point for asphalt grades.(7) This work was undertaken to get as broad information as possible on the relation of the viscosity of asphalt binders, measured in poises, to the stability of laboratory mixtures as measured by the direct compression test. For this work, asphalts of three penetration grades (60-70, 85-100, 120-150) from different sources and with widely different characteristics were used. Differences in composition and shear susceptibility were present as well as differences in viscosity-temperature susceptibility. Three types of aggregate were also used to make the specimens with each asphalt. These were sand, gravel, and crushed stone. Figure 3 shows a plot of strength vs. temperature for the 85-100 grade asphalt having the lowest viscosity-temperature susceptibility (asphalt no. 3) and the asphalt having the highest viscosity-temperature susceptibility (asphalt no. 69).

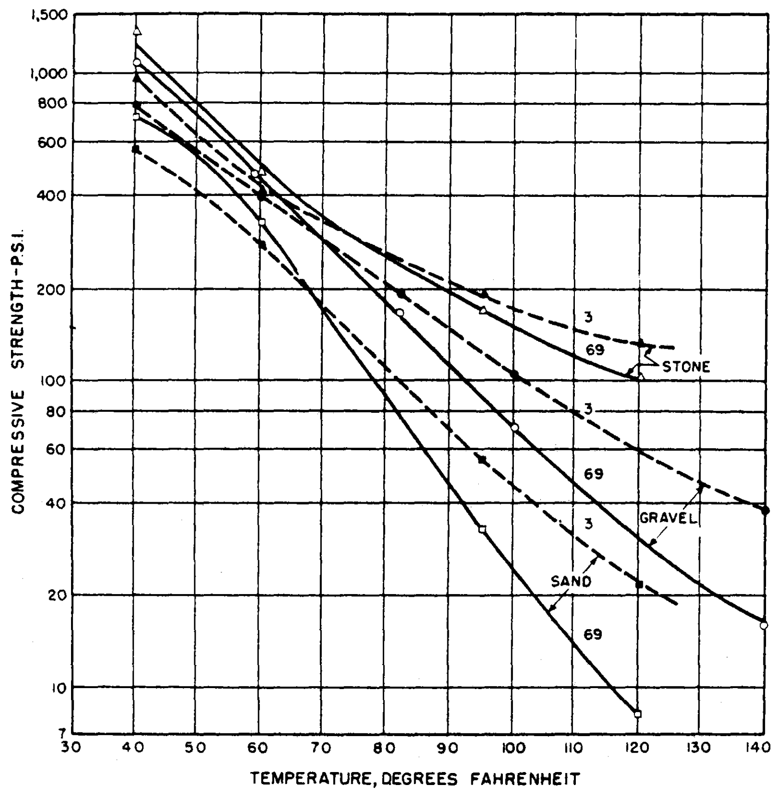

Figure 3. Relation between log strength and temperature — different aggregates and asphalts. (From reference 7.)

This figure illustrates several significant facts. First, the three aggregates, which vary significantly in internal friction or interlocking capabilities, form distinctly different curves with both asphalts. At 120°F, which is not as hot as the pavement gets on many summer days, the compressive strengths of the specimens containing the most temperature-susceptible asphalt ranged from about 8 psi with sand to 102 psi with crushed stone. For specimens made with the least temperature-susceptible asphalt, corresponding differences ranged from 21 psi to 133 psi. These data also illustrate that, on a percentage basis, the differences between strengths of specimens for asphalt of different consistencies are minimized by the use of aggregate with high internal friction.

Figure 4 illustrates differences that can occur with different penetration grades of asphalts from the same or different sources. The lines for each grade of asphalt from the same source are essentially parallel, but the slopes of the lines differ significantly for asphalts of different sources. It is significant that at 140°F — the temperature at which trial pavement mixes are usually tested for stability in pavement design-specimens made with the 120-150 grade of the low temperature-susceptible material had essentially the same average strength as the specimens made with the 60-70 penetration grade of the high temperature-susceptible material.

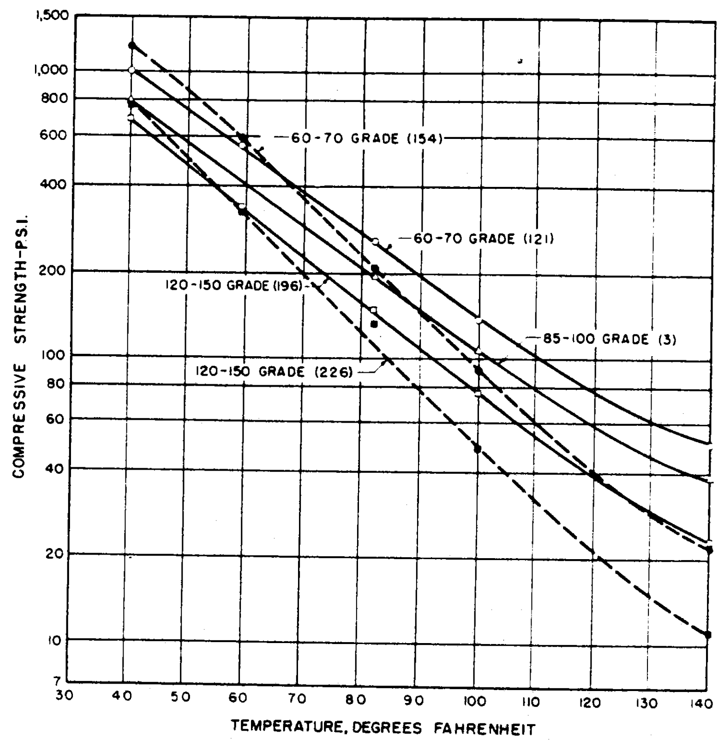

Figure 4. Relation between log strength and temperature — asphalts of different grades. (From reference 7.)

Relation of Viscosity to Strength

Figure 5 illustrates the relation between the viscosity of the asphalt and the strength of specimens. The viscosities shown are from the asphalts recovered from the test specimens, not from asphalt prior to mixing. As indicated, data from 10 asphalts from 6 sources representing the largest differences in characteristics measured in the BPR's study of asphalt characteristics are included. The data points for specimens made with the same aggregate all fall on the same curve, regardless of the grade or source of the asphalt or the temperature at which the test was made. Several important observations can be made from these curves. One observation is that for different aggregates the differences in strengths on a percentage basis are larger at lower viscosities (corresponding to higher temperatures). A second observation is that the properties of the asphalt are more critical to the strength of the mix at higher temperatures than at lower temperatures. Inasmuch as 140°F represents a point near the maximum summer temperature of the pavement and the temperature at which trial pavement mixtures are tested during design, it appears reasonable that this should be the point at which grades should be controlled. This temperature also is a relatively convenient one for making the viscosity test. In addition, controlling grade at this temperature minimizes differences at the normal compaction and mixing temperature between asphalts of different viscosity-temperature susceptibilities. It should also be noted that at 140°F all pavement asphalts exhibit essentially Newtonian flow; that is, they can be called true liquids. Thus, problems from shear susceptibility do not arise.

However, by shifting grade control from 77°F to 140°F greater differences between materials of the same viscosity grade and with different temperature susceptibilities will occur at low service temperatures than occur for the penetration grades from these same sources. This fact is often stressed by those favoring either penetration grading at 77°F or a grading system based on the viscosity at 77°F. They also point out that a large body of experience is based on the penetration at 77°F.

It is necessary to review the effects of this change from the standpoint of the engineering and design problems that must be faced.

The first point to keep in mind is that whether penetration grading or viscosity grading is being used, the same body of material — the bottom of the petroleum barrel, so to speak — is the raw material for manufacturing highway asphalts. Expressed another way, the pie is the same, it is only sliced differently. Consequently, if difficulties are encountered with a given source of asphalt in designing a mixture that is at the same time stiff enough to avoid rutting and shoving at the highest temperatures and not so stiff at the lowest temperatures that excess brittleness and cracking occur, these difficulties will be encountered and must be addressed whether penetration grading at 77°F or viscosity grading at 140°F is employed.

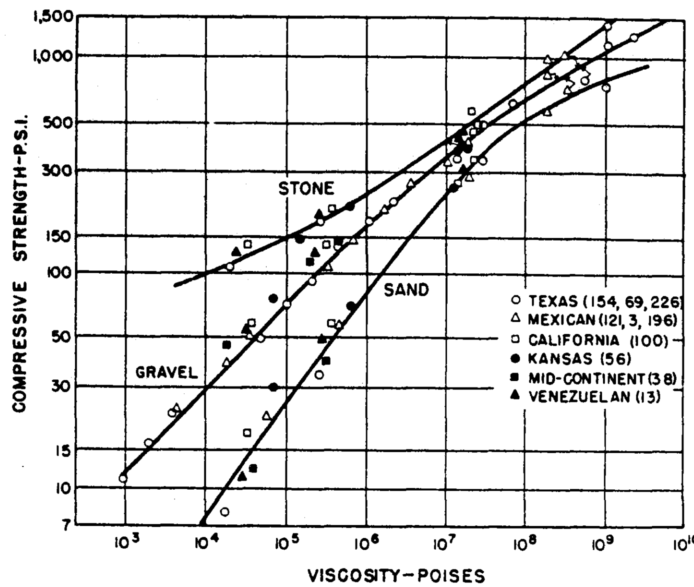

Figure 5. Relation between log strength and log viscosity of asphalt. (From reference 7.)

Effects of Viscosity-Temperature Susceptibility

Before considering this thought further, the overall picture of viscosity-temperature susceptibility of highway asphalts should be considered.

Figures 6 and 7 illustrate the overall viscosity-temperature relationships of asphalts from different sources. The lines shown represent the extremes of viscosity-temperature susceptibilities and shear susceptibilities for the asphalts included in a BPR study.(5) According to theory, first developed by Walther for viscous Newtonian liquids, a plot of the logarithm of the logarithm of viscosity in centipoises against the logarithm of absolute temperature is a straight line. This relationship is the basis for the ASTM viscosity-temperature chart for asphalt. Consequently, in studying asphalt rheology it is customary to determine the viscosity at two or three points and extrapolate or interpolate values at other temperatures based on a straight line between the points plotted on the ASTM chart. As shown in Figures 6 and 7, this relationship seldom holds perfectly for any asphalt and for some the deviation is very wide. The same set of data was used to construct both figures, but in Figure 6 a shear rate of .05 sec^{-1} was used to calculate apparent viscosity. In Figure 7 the limiting viscosity is plotted. This is the viscosity at which the shear rate is sufficiently low so that Newtonian flow is attained. A comparison of the apparent viscosities at the same temperatures for the same materials but the different shear rates in Figure 7 with Figure 6 illustrates the large differences that shear susceptibility can cause. Failure to recognize this effect as well as the significant deviation from a straight-line relationship can create problems in making comparisons of extrapolated data for different asphalts.

Asphalt technologists have long sought a way of expressing the viscosity-temperature relationship as a simple index. Several such indices that are often used were discussed in the report on a recent study of asphalt properties by the Asphalt Institute.(8) That study found that there was not a good relationship between the various indices. While it is not possible to discuss these indices in detail here, an examination of the basis for each of them in relation to the overall viscosity-temperature relationship indicated by Figures 6 and 7 easily explains why there is no agreement.

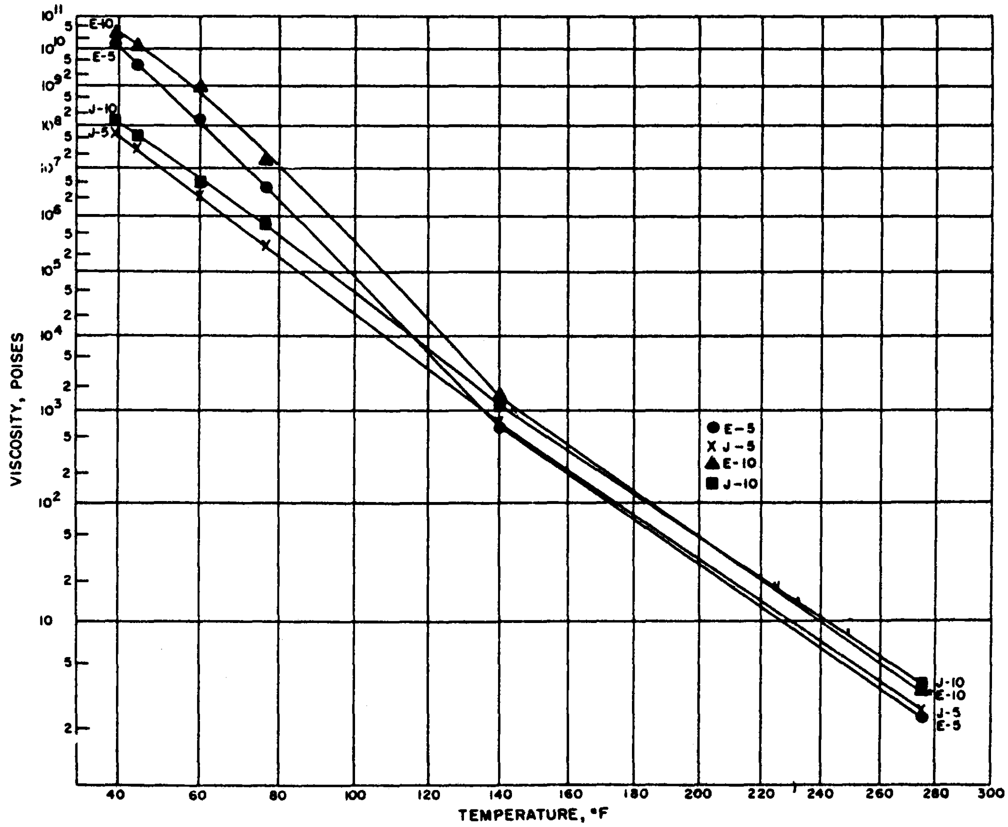

Figure 6. Viscosity (0.05 sec.$^{-1}$ shear rate) and temperature relation for selected asphalt cements. (From reference 5.)

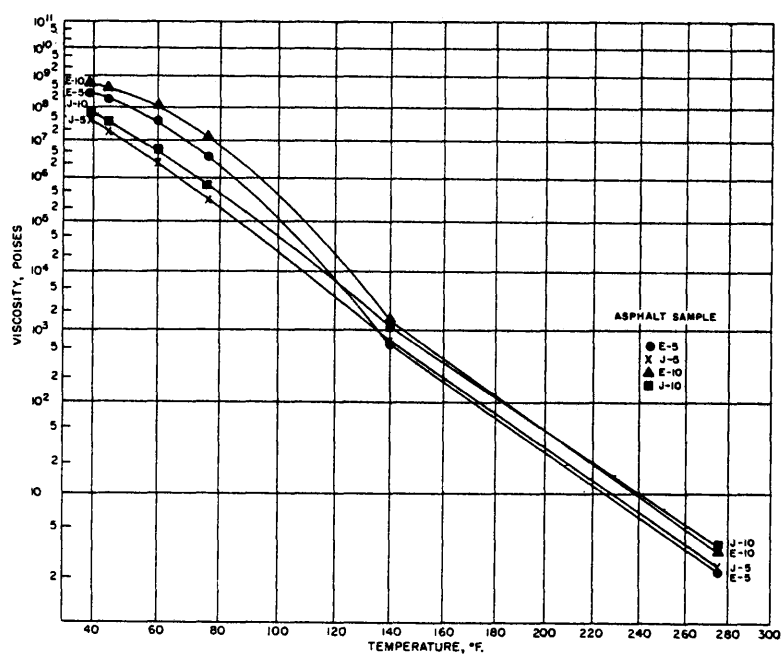

Figure 7. Limiting viscosity and temperature relation for selected asphalt cements. (From reference 5.)

The penetration index which is often used is an empirical number based on an assumption that all asphalts have the same penetration, 800, at their softening points. It deals with a relatively narrow band of temperatures. The original concept was based on the measurement of penetration at 77°F and the softening point of the material, which usually occurs a little above 100°F for most paving asphalts. In the Asphalt Institute work, the plotted data were based on the slope of the log penetration versus temperature line based on penetrations at 77°F and 40°F. The penetration-viscosity number is based on the penetration at 77°F and viscosity at either 140°F or 275°F. The Asphalt Institute report uses viscosity at 275°F to calculate values. Finally, the viscosity-temperature susceptibility based on the slope of the plotted line on the Walther chart is usually considered over the 140°F to 275°F range. As shown in Figure 6, asphalts change in viscosity-temperature susceptibility from one range to another and the degree of change can vary from asphalt to asphalt. Consequently, one should expect indices established over different temperature ranges to be different. If the consistency changes between the high and low temperatures being used for determining any of these indices are essentially linear between the temperatures chosen, they may have an engineering value in establishing the relative changes for different asphalts in that specific temperature range. However, such a linear relation is not always present. For example, a penetration-viscosity number calculated on the basis of the penetration at 77°F and a vicosity at 275°F completely ignores the possibility of the sharp break in the viscosity-temperature line that often occurs between 275° and 77°F. These data clearly indicate that if viscosity-temperature relationships are of concern, decisions should be based on real data over a wide range of temperatures and also, at low temperatures, over a wide range of shear susceptibilities, rather than on empirical indices.

Practical Effect of Changing Viscosity-Temperature Susceptibility of Asphalt

Because there is considerable support for retaining penetration grading at 77°F (or establishing viscosity grading at 77°F) in lieu of viscosity grading at 140°F, it is of interest to examine the broad effect of these two approaches when dealing with practical engineering problems.

Consider the effect of a shift from the lowest viscosity-temperature susceptibility to the highest under each system. Assume that both Agency A and Agency B are using an asphalt that would be classed as having a low viscosity-temperature susceptibility and that Agency B is using 85-100 penetration and Agency B AC-10. It is quite possible that for this source both materials could be supplied from the same tank.

Now suppose that the supply of low viscosity-temperature susceptibility material is exhausted and the only available material is one with a very high temperature susceptibility and that each agency continues to use the initial grades of asphalt — Agency A the 85-100 and Agency B the AC-10. What happens?

Agency A suddenly finds that it has all sorts of problems during mixing and compaction. Adjustments during construction can be made by reducing temperatures, but if summer temperatures are high, rutting, shoving and, possibly, bleeding of the pavement may occur. However, low temperature properties do not seem to have been appreciably affected.

Agency B, on the other hand, may not note any difference in mixing and compaction, but if it is in an area where very low winter temperatures occur it will note an increase in cracking of their pavements. A check with the supplier will show that he no longer supplies the 85-100 and AC-10 from the same tank. The 85-100 now probably comes from the AC-5 tank or, conversely, the AC-10 comes from the 40-50 penetration grade tank.

Obviously, a shift in the source of supply involving significant changes in viscosity-temperature susceptibility has the potential for creating problems — and neither penetration grading nor viscosity grading serves as a means of avoiding them. If Agency B is in the north, for example, in Canada, there is a good possibility that it may decide that grading at 77°F is the best system for it to use. If Agency B is in an area with a mild climate, it will most likely prefer to continue using the AC-10, since very cold temperatures are of little concern. However, if either agency must take into account both very low temperatures and very high summer temperatures, something must be done. One option is to place some restrictions on the viscosity-temperature susceptibility so that a material with the very high temperature susceptibilities will not be acceptable. Such limits must be realistic from the standpoint of the characteristics of available materials.

A second option of adjusting the grade of asphalt used to accommodate the conditions encountered is also possible in both cases. However, present supply conditions make the exercise of this option very difficult, unless a change is made for an entire state or a region. Asphalt suppliers will not generally make different grades available on a job-to-job basis, but insist on supplying a single grade to a given market. This situation takes away from the asphalt mix designer a valuable capability for adjustment and can force the use of a less than optimum asphalt consistency — opening the possibilites for difficulties.

It is noted that the ASTM and AASHTO specifications for penetration grading do not contain any limitations on the viscosity-temperature susceptibility, although some states and provinces in Canada place a minimum limit on viscosity at 275°F to rule out the extremely temperature-susceptible materials. Under the viscosity grading system, temperature susceptibility is limited by a minimum viscosity at 275°F and a minimum penetration at 77°F (maximum consistency) in addition to the minimum and maximum for each grade at 140°F. The limits set are based on characteristics of available materials. At the time the specifications were adopted the limits of Table 1 of AASHTO M226 were established on the basis of the asphalts previously in use over the entire U. S. . The limits of Table 2 in the AASHTO specification are more restrictive in terms of viscosity-temperature susceptibility and are based somewhat on the characteristics of asphalts that were predominantly used in many areas of the country (especially on the East Coast) at the time of their adoption. The requirements in Table 3 of the same specification are based on the West Coast approach, which establishes the grade of asphalt on the basis of the viscosity of the residue from the rolling thin film oven test. On the West Coast, specification limits on the viscosity-temperature susceptibility are also established on the basis of the residue from the rolling thin film oven test.

Effects of Limits on Viscosity-Temperature Susceptibility

An examination of data from the latest Asphalt Institute study indicates the extremes of viscosity-temperature susceptibility being supplied by these specifications and permits an assessment of their significance. A good range for asphalt viscosity for mixing is considered to be from 150 to 300 centistokes. If the optimum is assumed to be 200 centistokes (equivalent to 2 poises), the Asphalt Institute data show that the most temperature-susceptibile AC-20 has that viscosity at 292°F, and that the least temperature-susceptible AC-20 has this optimum viscosity at 307°F. In most specifications the allowable spread in mixing temperatures is the target value ± 20°F. Consequently, the 15°F spread indicated here for the extremes is hardly significant. Similarly, when the range of temperatures for the optimum compaction viscosity of 20,000 centistokes (equivalent to 200 poises) is examined, the most susceptible asphalt has this viscosity at a temperature of 173°F and the least susceptible has it at 179°F. This 6°F spread is certainly of no concern from the construction standpoint.

At low temperatures, the range of temperatures for equal apparent viscosities is relatively large. However, the concern is not with such differences. The concern is whether or not the hardest material forms a mixture that is not so stiff that excessive cracking occurs at the lowest temperatures encountered. A detailed discussion of what this critical stiffness should be is beyond the scope of this presentation and more is involved than just the apparent asphalt viscosity.

The basic problem is to design a mixture that has adequate stability at the highest summer temperatures to avoid rutting and shoving and that at the same time is not so stiff or brittle at low temperatures that cracking occurs. A number of factors are involved in this problem including aggregate type and gradation, percentage of asphalt used, and the range of ambient temperatures expected in service, as well as the characteristics of the asphalt binder. However, some ball-park figures of critical temperatures can be obtained by reference to the work of Gaw.(9) Based on his calculated critical stiffness, which he derives from Heukelom's stiffness nomograph and the relationship between the penetration at 77°F and penetration at 41°F, it can be shown that an AC-20 with the minimum allowable penetration of 40 would have its critical stiffness at -4°F. If the Table 2 limit of 60 is used, the critical stiffness is at -26°F. The Asphalt Institute data for AC-20's now on the market show that the critical stiffness of the most viscosity-temperature susceptible material would be -26°F and that for the least viscosity-temperature susceptibility -44°F.

To summarize, while it cannot be stated that an asphalt specification based on penetration grading at 77°F with some minimum control on the viscosity at high temperatures will not provide an adequate grading system, the system based on viscosity grading at 140°F with a minimum limit on the viscosity at high temperatures and a maximum limit on consistency at a service temperature (now controlled by penetration at 77°F) is believed to be more advantageous for conditions encountered in the U. S. Such a system tends to minimize differences in handling characteristics of different materials during construction of the highway. The possibility of varied performance at low ambient temperatures exists, but the problem of avoiding excessive stiffness at low temperatures is one of mix design and asphalt grade selection. If the proper asphalt grade selection is made, this problem can be dealt with under a viscosity grading system at 140°F as well as with the penetration system at 77°F.

The Durability Aspect

In highway construction the durability of the pavement is of concern. That is, How long does it perform its intended purpose without excessive deterioration? It is known that many factors enter into such durability, including type and gradation of the aggregate and the amount and consistency of the asphalt used. Accordingly, the durability of the asphalt cement itself is difficult to define. However, it generally is considered to relate to how well the asphalt retains its original characteristics during the construction of the pavement and during its service. For specification purposes, the resistance to change during the thin film oven test is considered related to asphalt durability. Such resistance to change should be considered from the standpoint of changes in ductility as well as changes in consistency.

Significance of the Thin Film Oven Test

The thin film oven test was developed in 1940 by the BPR as a means for measuring the relative hardening characteristics of asphalt cements during mixing.[10] It replaced the "regular" loss test earlier used as a volatilization test. The original test was developed to control the volatility of fluxing materials for Trinidad asphalts and is not appropriate for petroleum asphalts. When it was first introduced, there was opposition to the thin film test primarily on the basis that the conditions of the test didn't "match" either performance conditions or conditions during service. However, the 1/8-inch thickness, and 5-hour time were established by trial and error from tests at a number of thicknesses and for a number of periods of time. The temperature of 325°F was carried over from the initial test, since it represented a "normal" upper limit of mixing temperature. Hardening can occur during mixing of an asphalt in a pugmill from both oxidation and volatilization. The relative amount of hardening from each cause varies depending on the source and method of refining of the asphalt. In the development of the test, it was found that the 1/8-inch film and 5-hour test was the combination of conditions that most nearly matched the hardening that occurred during mixing of an 85-100 penetration asphalt at 300°F.

It should be pointed out that the amount of hardening during the test does not necessarily equal hardening in the pugmill when materials either harder or softer than 85-100 are tested. Changes in the temperature of the mixing would also affect the actual hardening. It would be expected that a material softer than an 85-100 or AC-10 that is mixed at a temperature appreciably lower than 300°F would not actually harden as much during mixing as in the thin film oven test. Conversely, a material mixed at a temperature greater than 300°F could harden more during mixing than in the thin film oven test. However, the relative amount of hardening for different asphalts under different conditions is shown by the relative amount of hardening in the thin film oven test.

The West Coast uses a rolling thin film oven test in lieu of the 1/8-inch thin film. This test was developed by Hveem in California, because he believed that the reactions occurring during the service of an asphalt in the pavement were more nearly duplicated by the much thinner film of his test, which approximates the film thickness of the asphalt in the pavement. The 75-minute time was chosen to provide about the same amount of hardening that occurred in a pugmill. Later comparative studies have shown that the two tests give about the same results and are interchangeable. The rolling thin film oven test has an advantage in the time required to make the test, 75 minutes as opposed to 5 hours, but a disadvantage in that the amount of material tested, 20 ml as opposed to 50 ml, requires more individual determinations if sufficient residue is to be obtained for a ductility determination.

Both AASHTO M226 and ASTM D3381 have ductility requirements for the thin film test residues. The universal use of the thin film test has eliminated from the market those materials having appreciable amounts of volatile constituents (2%-4%) that resulted in extreme hardening during mixing. It also prevents the use of materials that would lose ductility very rapidly during mixing or service in the pavement. The implications of a loss in ductility will be discussed in the following section. It is also noted that the grading of asphalt cement on the West Coast is based on the residue from the rolling thin film oven test. This is based on the concept that the residue consistency more nearly represents the consistency of the asphalt in the pavement immediately after laydown. Initial developmental work showed this to be generally true when based on pugmill mixing and temperatures then in general use. However, the introduction of drum-mixing may require a reassessment of whether or not this condition still holds.

Significance of Ductility

The ductility test was developed in 1903 by Dow and was part of the first "standard" specification for asphalt. It is without question the most controversial test in asphalt specifications. Some asphalt technologists believe that the test is an indication of a necessary property of asphalt related to its cohesive properties, or stickiness, but others consider the present laboratory test for ductility of no value for indicating the potential quality of an asphalt as a paving material. In a study reported in the 1963 Proceedings of the AAPT and also Public Roads,(11) it was shown that the consistency at which asphalt begins to lose ductility rapidly and the temperature at which such consistency occurs is a significant relationship affecting pavement performance. An examination of the available data from a number of experimental projects indicated that there is a critical ductility-penetration (or viscosity) relationship. When ductility for a given penetration exceeds this critical value, problems resulting from insufficient ductility are not likely to occur. If ductility is inadequate at the indicated consistency, failures from insufficient ductility can occur.

Most critics of ductility examine it at a given temperature and dismiss its importance. One reason given is that essentially all asphalts have ductilities at 77°F greater than 150 cm — the maximum length of most equipment for measuring ductility; therefore, they conclude that the requirement is not needed. A second reason is that the precision of the test is not acceptable. Others show a lack of correlation of ductility (usually measured at low temperatures) with service behavior. All of these reasons have some validity, but the conclusion that a ductility requirement is not needed for highway asphalts on these bases is not warranted. First, the ductility requirement that now appears in essentially all asphalt cement specifications for highways effectively eliminates from the market materials that in the absence of such a requirement could be supplied. Field experiments using materials with very short ductility in pavements have almost universally showed poor performance. Secondly, a linear type relationship between the amount of ductility and performance should not be expected. Ductility should be viewed on a go-no go basis. If the ductility is adequate, failure from this cause is eliminated, and doubling ductility wouldn't double service life and probably has little effect because failure or distress then would develop from other causes. Because of the go-no go approach, the poor precision of the test seldom creates problems in asphalt testing because once the use of materials unsuitable because of short ductility is eliminated, the suitable materials being supplied almost always exceed the acceptable limit by a wide margin.

In the late 1930's the BPR built a special ductility machine so that a length of pull of 250 cm could be attained. A wide range of speeds of pull was also available. Some of the results of tests made at different temperatures for asphalts from different sources are indicated in Figure 8. As can be seen, asphalt from different sources yield different shape curves but most of them have several things in common. One is that all materials reach a maximum, after which ductility decreases. This is because the thread of the material at high temperatures falls apart. The second characteristic is that at some temperature the ductility decreases very rapidly. For some materials this decrease is more rapid than for others, and it can be affected by the speed of pull. Certain asphalts at a given temperature have zero ductility when pulled at 1 cm per minute, but over 250 cm when pulled at 1/4 cm per minute. The really significant thing about the ductility relationship, however, is indicated by Figures 9, 10, and 11.[10] Figure 9 shows ductility plotted against the penetration of the material. The curves have about the same shape as in Figure 8. Figure 10 shows the ductility plotted against penetration for a number of different grades of steam or vacuum refined asphalts from a single source. As indicated, the results from all grades fall on the same curve. For asphalts from other sources, most likely refined by partial blowing, the ductility-penetration relationship is different for each grade as shown in Figure 11. These results show that the relationship of concern is the ductility for a given consistency rather than ductility for a given temperature.

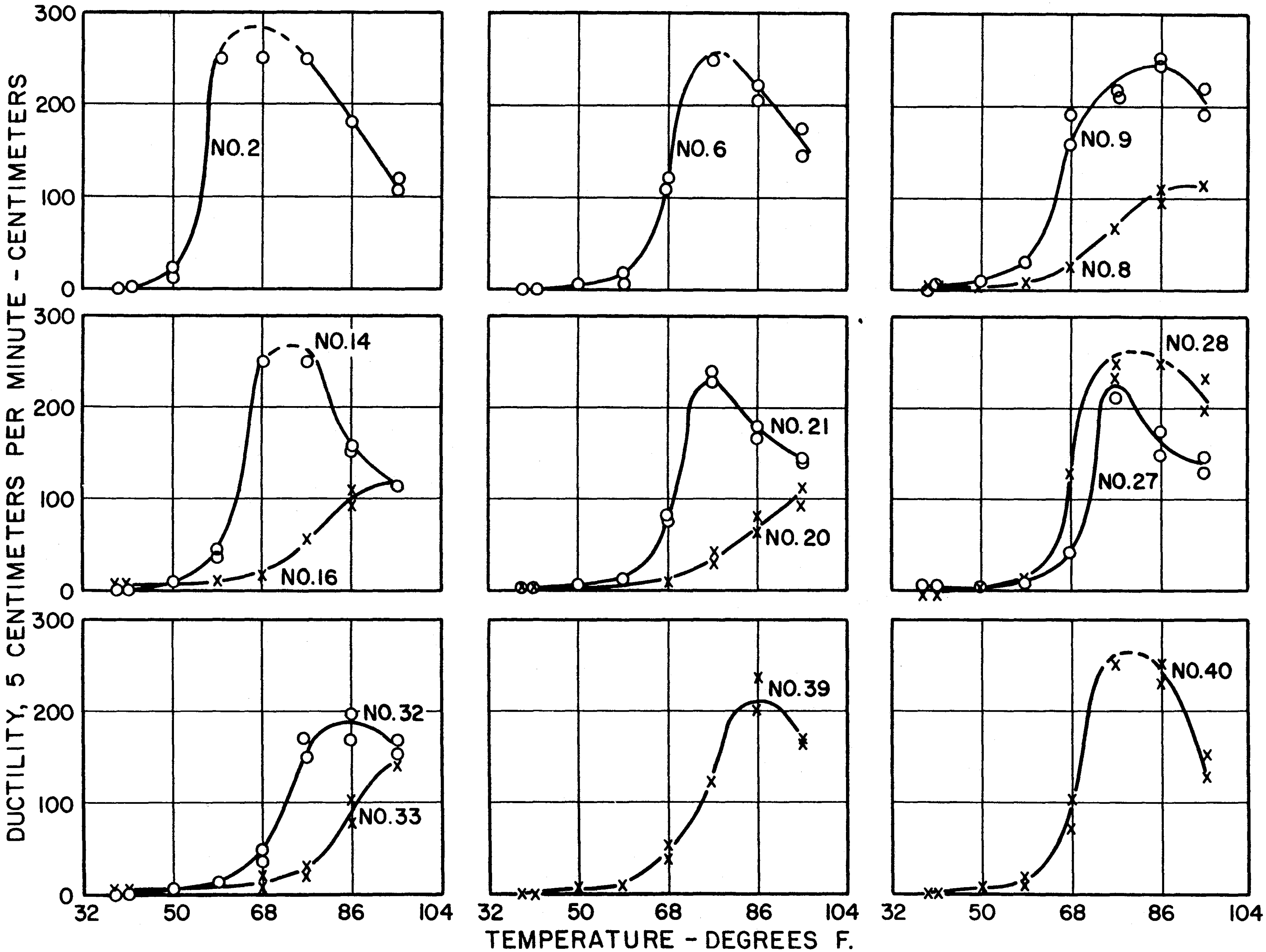

Figure 8. Relation between ductility and test temperatures of selected samples of 50-60 penetration asphalts. (From Reference 11.)

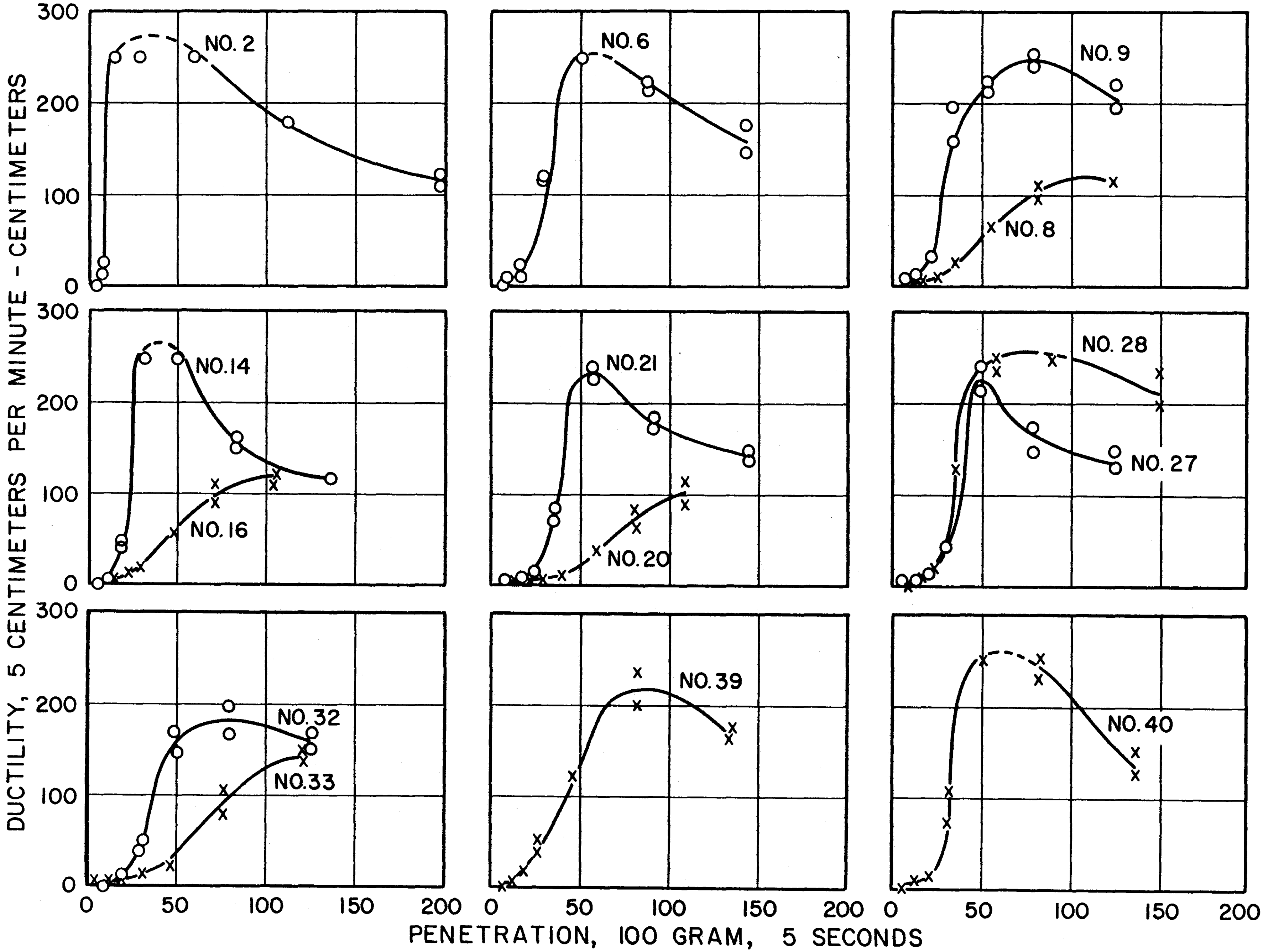

Figure 9. Ductility-penetration relation of selected samples of 50-60 penetration grade asphalts tested at different temperatures. (From reference 11.)

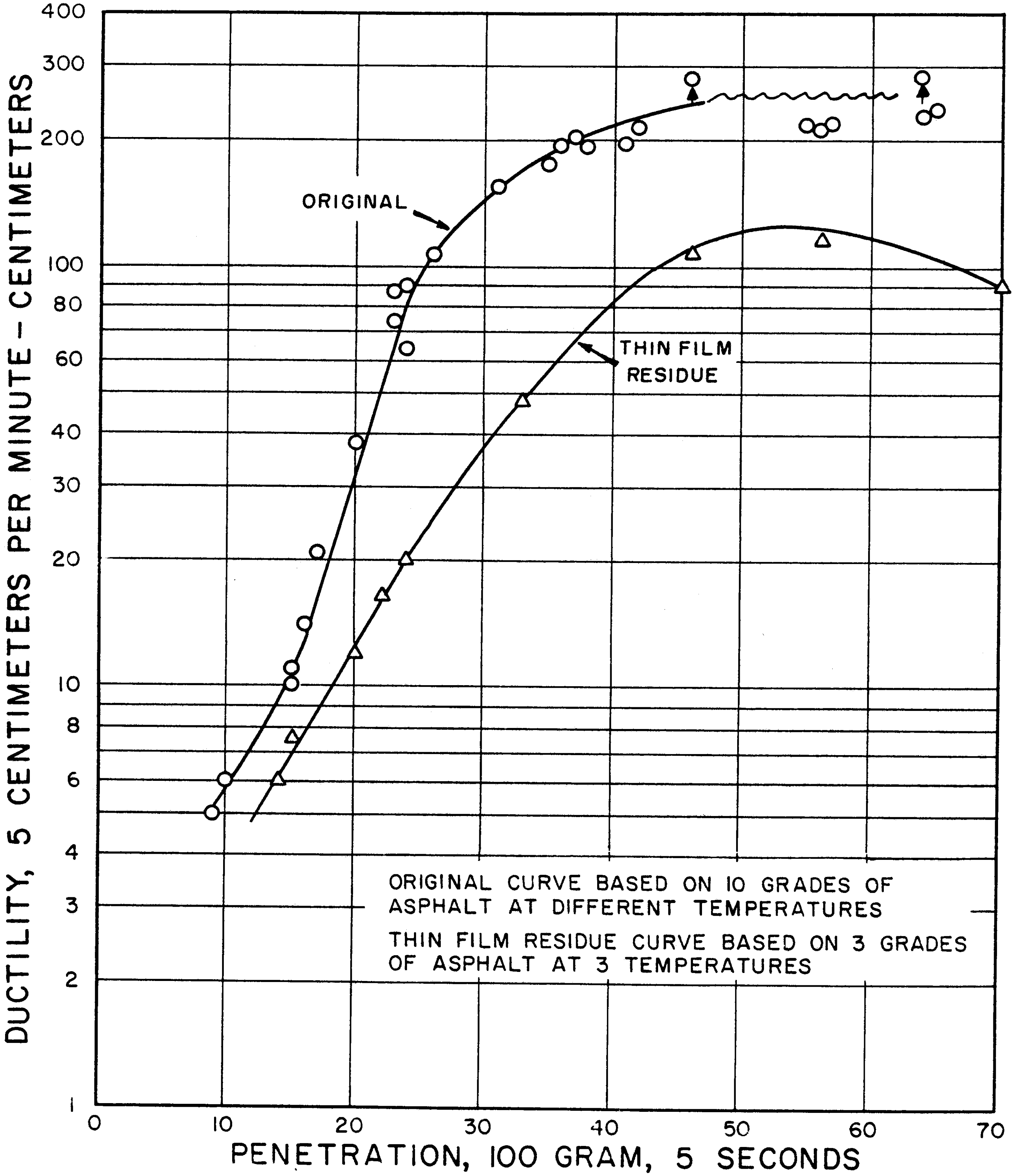

Figure 10. Ductility-penetration relation for asphalts of different grades refined from the same crude petroleum by steam and vacuum distillation. (From reference 11.)

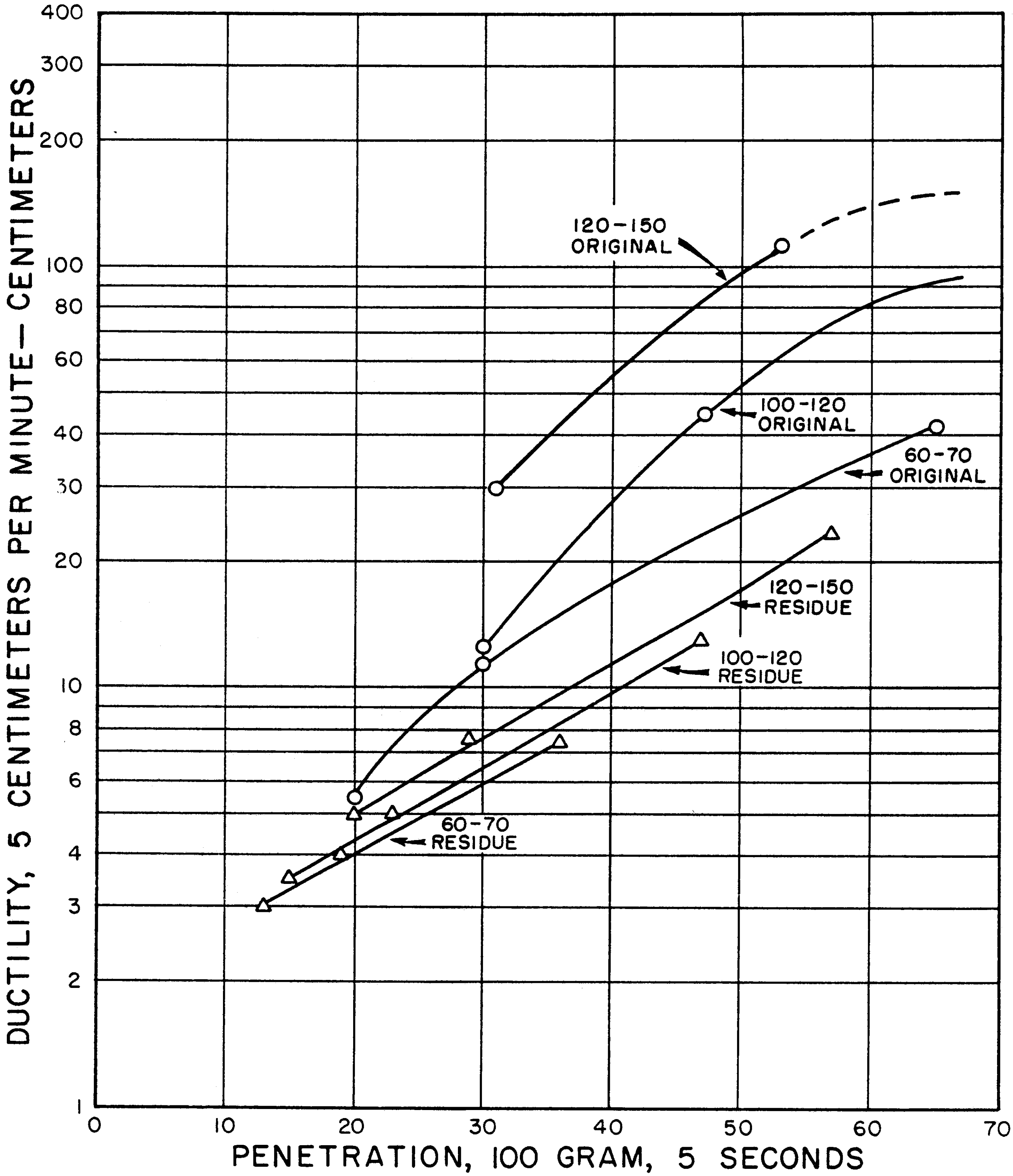

Figure 11. Ductility-penetration relation for asphalts of different grades prepared from the same crude that had some cracking and blowing during the manufacture. (From reference 11.)

An examination of data from a number of field experiments in the 1963 study showed that a lack of ductility likely contributed to poor performance when the ductility-penetration relationship fell below a curve approximately defined by a ductility of 20 cm at 30 cm penetration and a ductility of 100 cm at 50 cm penetration. These studies also showed that brittleness (very high viscosity or very low penetration) could be a cause of problems, even when the ductility-consistency relationship was adequate. Thus, ductility, or the lack of it, should not be considered as an indication of potential brittleness in a pavement. This is illustrated by data from several experimental projects as plotted in Figures 12, 13, and 14.

Figure 12 illustrates data obtained by the BPR from extensive studies of pavements. Project A showed severe localized failure between 1 and 3 years of service. Data points for this project are well below and to the right of the critical line for ductility-penetration. Consequently, the low ductility at a relatively high penetration is believed to have contributed significantly to the observed failure. Project B was a low traffic volume road built over a period of years by several contractors. The older sections of this project designated as B-1 were badly cracked, although riding qualities remained satisfactory. Extreme hardness of the asphalt in these sections undoubtedly was the main factor contributing to poor performance. Overheating of the asphalt during construction, along with high voids in the mix and very little traffic, may have been the cause of this rapid hardening. The data points for the two pavements that were in good condition at the time of the tests are of interest. Although greater hardening occurred in Project B-2 than in Project B-3, the ductility-penetration relation for the asphalt in Project B-2 was superior to that in B-3. Consequently, it would be expected that Project B-3 would fail earlier than B-2. Unfortunately, to the author's knowledge no follow-up study was made on these projects.

Figure 13 presents data from the Zaca-Wigmore studies in California. Asphalt E used in this section showed excessive hardening in the thin film oven test. The retained penetration was about 28 percent and the loss was 4.45 percent. As indicated by the data, the pavement residues had about the same ductility-penetration relationship as the thin film residues, and both were in the satisfactory zone. Consequently, it can be stated that the early failure (about 1 year) of these sections was caused by the rapid hardening of the asphalt because of its volatility.

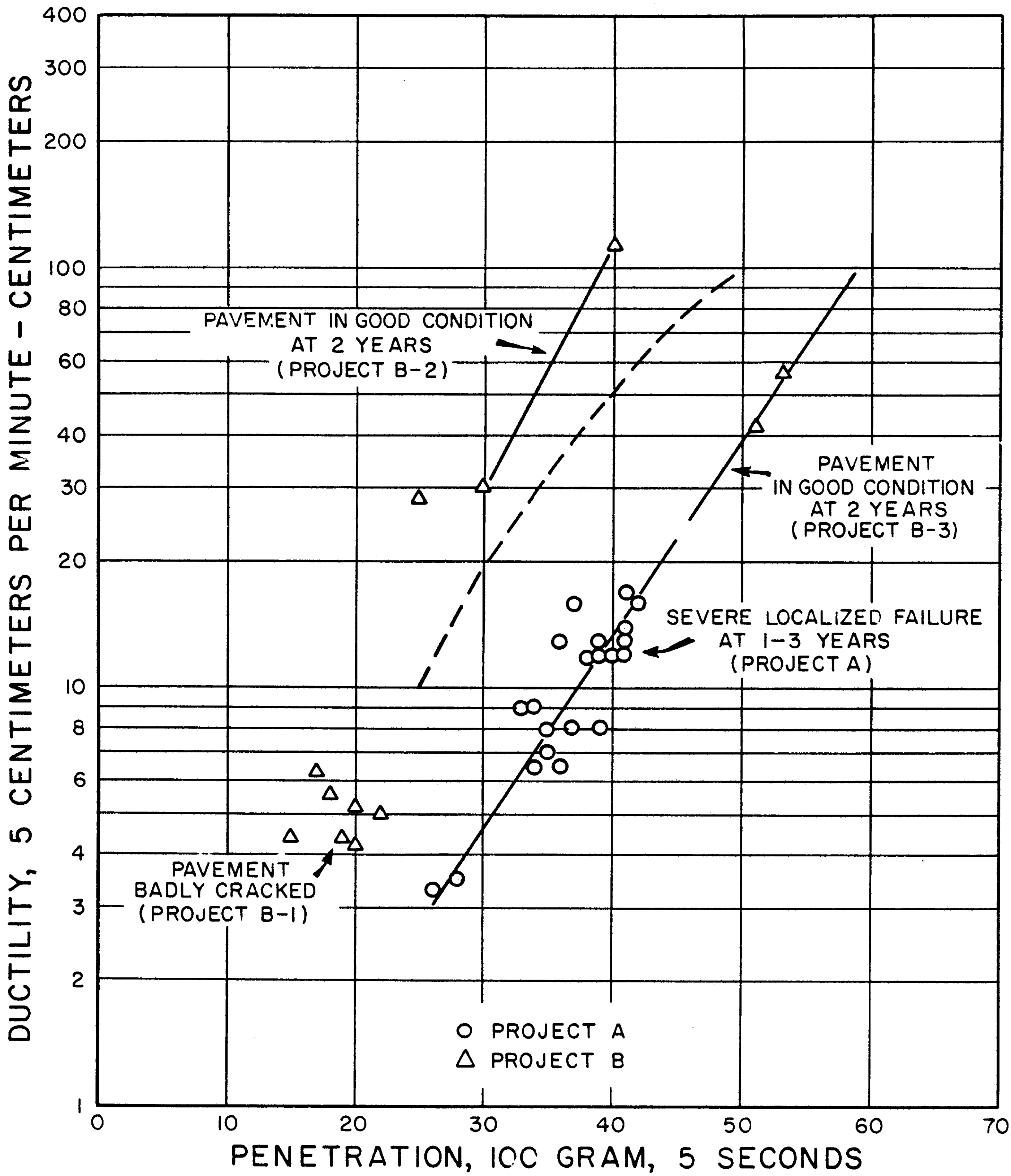

Figure 12. Ductility-penetration relation of asphalts recovered from pavement projects. Tests were made at 77°F. (From reference 11.)

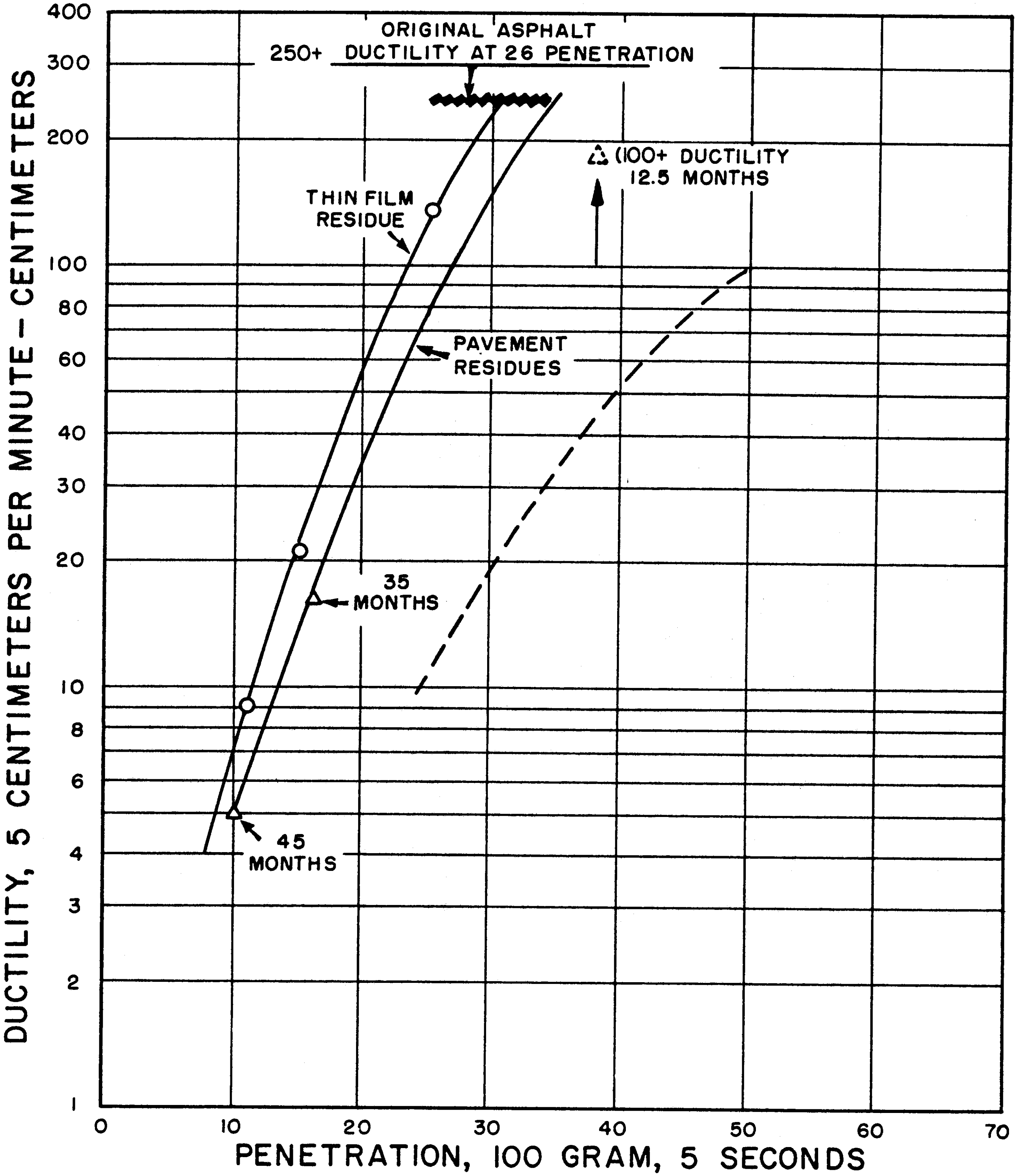

Figure 13. Ductility-penetration relation for asphalt E in Zaca-Wigmore experimental project. Tests on original asphalts and thin film residues were made at different temperatures, and those on asphalts recovered from pavement were made at 77°F. (From reference 11.)

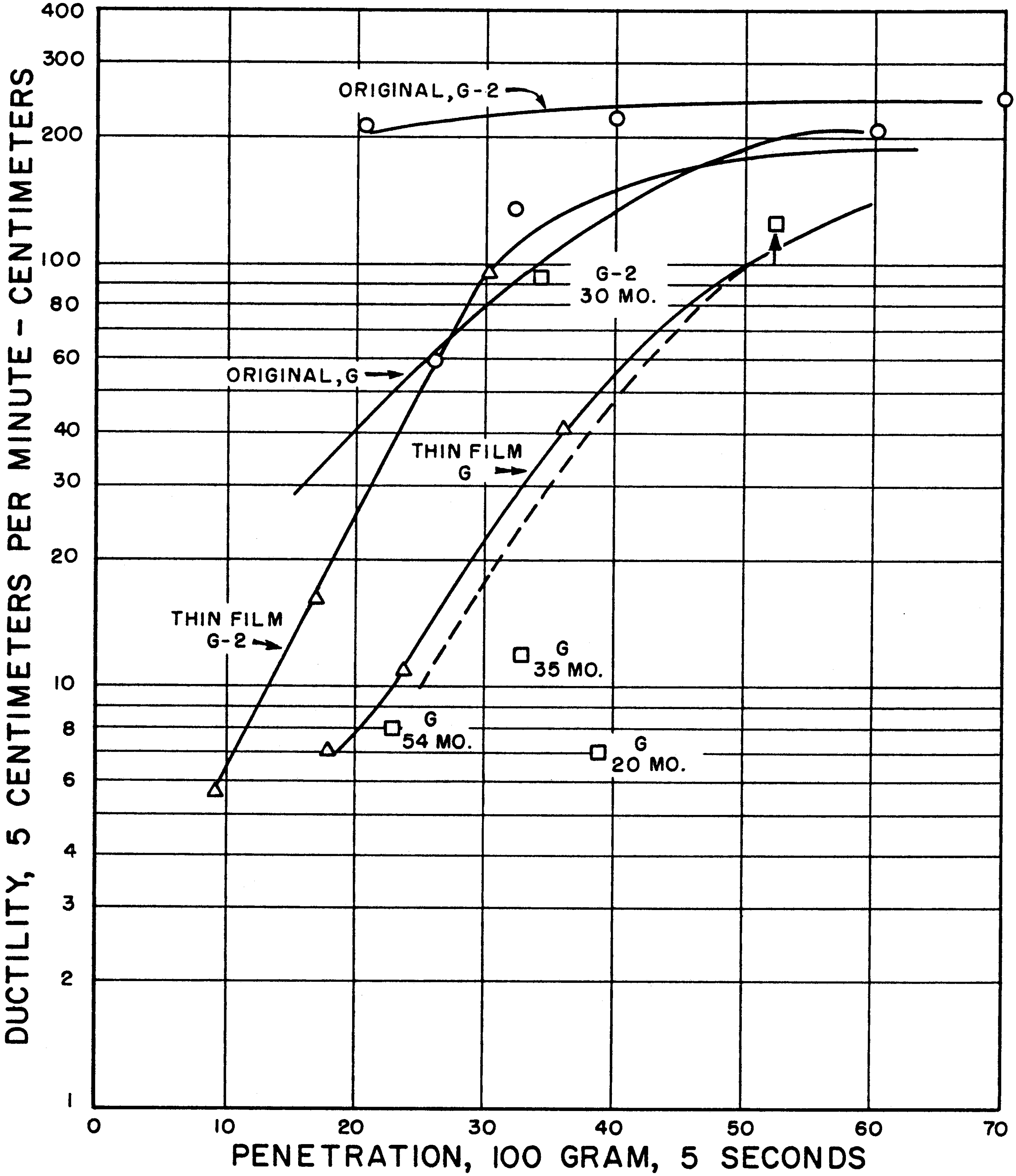

Figure 14. Ductility-penetration relation of asphalts used in sections G and G-2 of Zaca-Wigmore experimental project. Tests on original asphalts and thin film residues were made at different temperatures, and those on asphalts recovered from pavement were made at 77°F. (From reference 11.)

Figure 14 also shows data from the Zaca-Wigmore experimental project. Section G-2 was reported to perform significantly better than Section G, although the usual tests indicated that the asphalts were similar and similar performance was expected. However, the asphalt in Project G-2 had a ductility-penetration relationship definitely superior to that of the asphalt used in Project G, as indicated by the curves for the thin film oven test residues. At 30 months, the asphalt recovered from Section G-2 retained a satisfactory ductility-penetration relationship, while the data for the asphalts recovered from Section G at 20 months, 35 months, and 54 months all indicated unsatisfactory relationships.

Welborn and others have shown that ductility relates to the shear susceptibility of asphalts — which may in turn relate to the cohesiveness of the material as well as its rheology. Consequently, while there is no complete explanation of why, the bottom line appears to be that "sufficient" ductility is a must. Anything more than sufficient may not add anything in performance.

Other Specification Requirements

Other requirements usually found in specifications for asphalt cement are flash point, solubility, and, as an optional requirement, the Oliensis spot test. Flash point is retained primarily as an indication of how high the material may be heated before a potential fire hazard is created. It is useful from the standpoint of shipping regulations but has little significance from the standpoint of pavement quality. Solubility in trichloroethylene is a check for purity to avoid contamination with insoluble hydrocarbons. The Oliensis spot test is useful in eliminating highly cracked materials, which tend to harden rapidly in service. This test was most useful when refining processes employing cracking yielded residues of suitable consistency for manufacturing asphalt. However, under present conditions such materials are seldom encountered. The thin film oven test also provides adequate protection against cracked materials. Thus, the Oliensis test is now seldom required.

CONCLUSIONS

The conclusions to be drawn from this review of asphalt properties in relation to specification requirements are as follows:

1. Either penetration grading at 77°F with minimum limits on the viscosity at 275°F or viscosity grading at 140°F with limitations on the minimum penetration at 77°F will provide workable systems for establishing different consistency grades of asphalt.

2. In areas of temperate climate, the viscosity grading system is preferred because (a) it provides more uniform conditions during construction with asphalts of the same grade and different sources; and (b) under usual mix design temperatures and procedures, it guards against improper stabilities at hot summer temperatures.

3. In areas of extreme cold, special considerations in the mix design may be required to attain proper resistance of the pavement to thermal cracking, regardless of the type of grading system used. Under these conditions, viscosity grading at 140°F in lieu of penetration or viscosity grading at 77°F has a disadvantage. It increases viscosity differences at low temperatures for materials of the same grade but from different sources when such materials have significant differences in viscosity-temperature susceptibility. However, with proper limitations on viscosity-temperature susceptibility and proper asphalt grade selection, excessive stiffness at low temperatures can usually be avoided with viscosity grading as well as with penetration grading.

4. Although there is no exact relation between penetration and viscosity measured at the same temperature, estimates of viscosity from determined penetration (50°-85°F range), or estimates of penetration from determined viscosity, result in calculated values of sufficient precision for engineering purposes. The approximate relation for such estimates is

$$\log \text{viscosity in poises} = 10.0 - 2.0 \log \text{penetration}.$$

5. For a given aggregate system and asphalt content, the logarithm of the strength of specimens varies inversely with the logarithm of the viscosity of the contained asphalt, regardless of the source of the asphalt or the temperature at which the determination is made.

6. The relative durability of asphalt is measured by the thin film oven test or the rolling thin film oven test. Changes during either test approximate the changes occurring in a grade AC-10 asphalt when mixing is in a pugmill at 300°F. Actual changes for harder or softer materials may differ. Changes in type of mixing equipment or temperature of mixing may also produce different amounts of hardening.

7. Ductility is a significant property of an asphalt, and specifications for asphalt cements should contain minimum limits (preferably on the residue from the thin film oven test) for the length of pull at 5 cm per minute at 77°F. However, the significant property relating to

performance is the ductility for a given consistency. If the ductility at a penetration of 30 is below 20 cm, difficulties could arise from inadequate ductility. When ductilities are greater than this amount for equivalent penetrations, problems from inadequate ductility are not likely to occur.

8. Requirements for flash point and solubility in trichloroethylene are regulatory or contractual and have little or no bearing on the quality of an asphalt, other than detecting adulteration should it occur.

2606

REFERENCES

1. Krom, C. J., and G. M. Dorman, "Performance Requirements for Road Bitumens and Their Expression in Specifications", Shell International Petroleum Company, Limited, Amsterdam, Netherlands. (Paper presented to Sixth World Petroleum Congress, Frankfurt/Main, June 1963.)

2. Fromm, H. J., and Phang, W. A., "Temperature-Susceptibility Control in Asphalt-Cement Specifications", Highway Research Record No. 350, Symposium on Viscosity Grading of Asphalts, Highway Research Board, Washington, D. C., 1971

3. Griffith, J. M., and O. P. Puzinauskas, "Relation of Empirical Tests to Fundamental Viscosity of Asphalt-Cement", STP No. 328, Symposium on Fundamental Viscosity of Bituminous Materials, ASTM, Philadelphia, Pa., 1962.

4. Carre, G., and D. Laurent, "The Relationship Between the Penetration and Viscosity of Bitumens", Association Francais des Technicians du Petrole, Bull. 157, January 1963, Shell Bitumen Reprint 16.

5. Welborn, J. Y., E. R. Oglio, and J. A. Zenewitz, "A Study of Viscosity-Graded Asphalt Cement", Public Roads, Vol. 34, No. 2, Bureau of Public Roads, Washington, D. C.. (Also Proceedings, Association of Asphalt Paving Technologists, Vol. 35, 1966.)

6. Saal, R. N. J., and G. J. Koens, Journal of Institute of Petroleum Technologists, Vol. 19 (1933) p. 19.

7. Welborn, J. Y., W. J. Halstead, and R. E. Olsen, "Relation of Absolute Viscosity of Asphalt Binders to Stability of Asphalt Mixtures", Public Roads, Vol. 32, No. 6, Bureau of Public Roads, Washington, D. C., 1963. (Also STP No. 328, ASTM, Philadelphia, Pa.)

8. Puzinauskas, V. P., "Properties of Asphalt Cements", Proceedings, Association of Asphalt Paving Technologists, Vol. 48, 1979.

9. Gaw, W. J., "Measurement and Prediction of Asphalt Stiffness and Their Use in Developing Specifications to Control Low-Temperature Pavement Transverse Cracking", presented at Symposium on "Low Temperature Properties of Bituminous Paving Materials", ASTM, Chicago, Illinois, July 1976.

10. Lewis, R. H., and J. Y. Welborn, "The Properties of the Residues of 50-60 and 85-100 Penetration Asphalts from Oven Tests and Exposure", Public Roads, Vol. 22, No. 2, April 1941. (Also Proceedings, Association of Asphalt Paving Technologists, Vol. 10, 1941.)

11. Halstead, W. J., "Relation of Asphalt Ductility to Pavement Performance", Public Roads, Vol. 32, No. 10, Bureau of Public Roads, Washington, D. C.. (Also Proceedings, Association of Asphalt Paving Technologists, Vol. 32, 1963.)