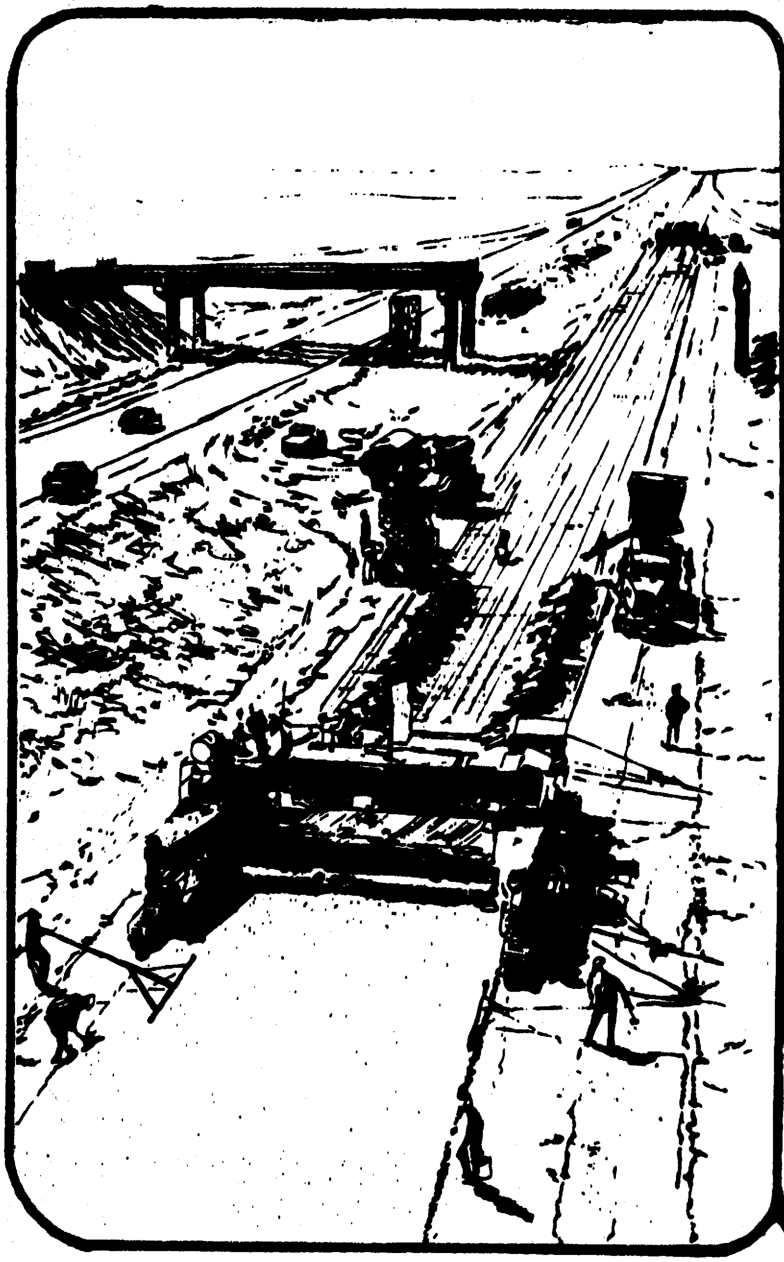
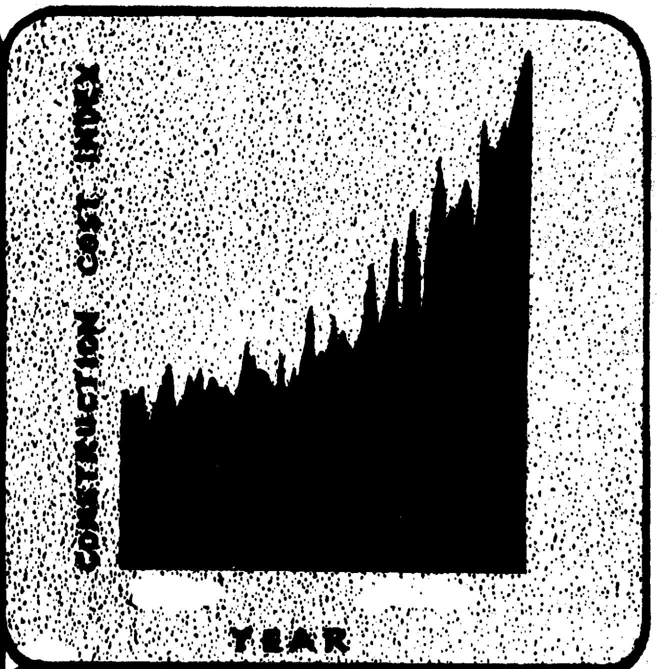
ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

SELECTION OF ASPHALT GRADE TO OPTIMIZE PERFORMANCE OF ASPHALT SURFACED PAVEMENTS

RESEARCH REPORT 214-27

JUNE 1980





COOPERATIVE RESEARCH PROJECT
2-9-74-214

"ENGINEERING, ECONOMY AND ENERGY
CONSIDERATIONS IN DESIGN,
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TEXAS STATE DEPARTMENT
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Research Report 214-27

Texas Transportation Institute
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June, 1981

TABLE OF CONTENTS

Summary 1
Introduction. 2
Asphalt Cement in Asphalt Concrete Mixtures 3
    Role of Asphalt Cement in Pavement Performance. 3
    Asphalt Properties. 6
        Chemical Properties 6
        Physical Properties 12
            Consistency 12
            Durability. 13
            Temperature Susceptibility. 15
            Ductility 15
            Flash Point and Solubility. 16
            Spot Test 17
    Changing Asphalt Properties: 1950-1980 17
        Asphalt Institute Study 18
        Pennsylvania State University Study 21
        Texas A&M University Study. 22
        Summary 23
Asphalt Specifications. 23
    Consistency and Temperature Susceptibility. 23
    Durability. 26
    Safety. 28
    Summary 29
Recommendations for Selection of Asphalt Grade for Asphalt Concrete 30
    Temperature 30
    Thickness of Asphalt Concrete 31
    Traffic 32
    Selection of Asphalt Grade - Examples 32
        Example No. 1 - District 1, Lamar County. 32
        Example No. 2 - District 4, Carson County 34
        Example No. 3 - District 20, Jefferson County 34
        Example No. 4 - District 5, Lubbock County. 35
    Summary 36
Recommendations for Selection of Asphalt Grade for Chip Seal Coats. 38
    Summary 40
References. 42

LIST OF TABLES

Table Page

1 Desirable Characteristics Associated with HMAC Performance 45

2 Typical Temperature Susceptibility Values for Asphalt Cements Utilized in Texas 46

3 Typical Properties of AC-3 Asphalt Cements Used in Texas - Spring 1981 47

4 Typical Properties of AC-5 Asphalt Cements Used in Texas - Spring 1981 48

5 Typical Properties of AC-10 Asphalt Cements Used in Texas - Spring 1981 49

6 Typical Properties of AC-20 Asphalt Cements Used in Texas - Spring 1981 50

7 Texas State Department of Highways and Public Transportation - Standard Specifications for Asphalt Cement (1972) 51

8 "Critical" Ductility-Penetration for Field Aged Asphalts . . . 52

9 Guide for Selection of Asphalt Grade to Prevent Low Temperature Cracking. 53

10 Recommendations for Selection of Asphalt Cement 54

11 Approximate Relationship of Air Temperatures to Pavement Surface Temperatures 55

12 Comparison of Asphalt Product Types Used for Surface Treatments and Seal Coats 56

13 General Recommendation for Asphalt Selection Based on Climatic Conditions 57

14 Temperature Limitations for Asphalt Selection at the Time of Construction 58

15 General Recommendations for Asphalt Selection Based on Aggregate Type 59

LIST OF FIGURES

Figure		Page
1	Relation of Retained Penetration After Field Aging to Air Voids	60
2	Viscosity - Temperature Relationship for AC-5 Asphalts	61
3	Relationship Between Viscosity at 60°C (140 F) and Penetration at 25°C (77 F) For Asphalts Cements	62
4	Relationship Between Viscosity At 60°C (140°F) and 135°C (275°F) For Asphalt Cements	63
5	Relationship Between Viscosity At 60°C (140°F) for Original and Heated Asphalt Cements	64
6	Effect of TFOT Heating on Penetration at 25°C (77°F) for Asphalt Cements	65
7	Allowable Minimum Temperature for AC-5 Asphalts	66
8	Allowable Minimum Temperature for AC-10 Asphalts	67
9	Chart for Selecting Grades of Asphalt Cement to Avoid Low-Temperature Transverse Pavement Cracking	68
10	Minimum Temperature in Texas During the Period 1951-1980	69
11	Maximum Temperature in Texas During the Period 1951-1980	70
12	Climate Zones Associated with Selection of Asphalt Type for Seal Coats	71
13	Aggregate Type Classification Chart (After Reference 34)	72

SUMMARY

The choice of the proper asphalt for a particular project is an engineering decision which should be made carefully. Factors such as temperature, traffic, thickness of the layer and construction conditions should be considered. Since the selection of the asphalt will influence construction and performance, the engineers need to have a knowledge of asphalt properties influencing the selection, together with a background of information which can be an assistance in making the selection.

In making a selection the decision is limited by two major constraints: (1) the choices available in the Standard Specifications and (2) the inherent properties of the asphalt not specifically covered by the specifications. However, within these constraints there is usually a preferred type or grade which is available for a particular project.

Based on data developed in Texas and by other investigating agencies, the two major considerations for the selection of asphalt for asphalt concrete are: (1) durability and (2) temperature susceptibility. The selection of type and grade for seal coats and surface treatments involves eight considerations, each of which is discussed briefly in the report.

Construction procedures, asphalt cement film thickness, mixture air void content and asphalt physical-chemical properties among other factors control the rate of hardening of asphalt cements. Hardening of asphalts with time (durability) should be controlled within acceptable limits.

The temperature susceptibility of asphalt will influence the mixing, and compaction as well as high and low temperature performance of asphalt concrete. Asphalts used in Texas exhibit a wide range of temperature susceptibility. Also, within a given grade of asphalt the temperature

susceptibility can vary considerably depending on the source of the asphalt.

Criteria for selection of asphalt to minimize low temperature (transverse) cracking have been developed and can be used to select the appropriate grade. In some situations it will be desirable to consider using an AC-5 grade to minimize transverse cracking. Harder grades of asphalt cement are recommended for higher traffic volume facilities and for the thicker sections of asphalt concrete.

This report attempts to provide a background of information useful in selecting types and grades for asphalt concrete, seal coats and surface treatments.

In addition to asphalt type and grade selection, the report emphasizes the need for careful development of asphalt concrete mixture design requirements, seal coat and surface treatment spread rates and construction procedures as part of the overall planning activity. Field investigations generally indicate that these factors are significant and can be of greater importance than the type and grade of asphalt cement.

INTRODUCTION

There is little or no disagreement among pavement engineers that the properties of the asphalt cement will influence the performance of asphalt concrete surfaced pavements. In a general way there is also some consensus regarding the desired characteristics of asphalt for use in asphalt concrete. For example, asphalt properties should remain constant, or nearly so, with time (durability); asphalt should have good adhesion with aggregate, particularly in the presence of water and moisture vapor; it should not be highly temperature susceptible under ambient conditions (i.e., 120^{O}F to -30^{O}F) but should be increasingly temperature susceptible at temperatures above 170°F. Asphalt should also be flexible under both long and short loading times (e.g., environmental and traffic loads). These are ideal characteristics of asphalt cements and they are difficult to obtain in the real world.

Engineers must recognize certain limitations and the state-of-the-art with regards to the ability to produce an asphalt cement with the desired characteristics, and also the ability of engineers and chemists to define these characteristics in terms of materials properties. Furthermore, it is necessary to translate desired characteristics and properties into a reasonable set of specifications compatible with the manufacture of the product at a cost which is competitive for highway construction.

In the subsequent sections of this report an effort will be made to review (1) the role of asphalt cement in pavement performance, (2) asphalt properties, (3) asphalt specifications and (4) guidelines for selection of asphalt type and grade. Asphalt grade selections will be illustrated by specific examples applicable to several geographical areas in Texas. The report is divided into two parts: first dealing with asphalt in Hot Mix Asphalt Concrete, and second, the role of asphalt in surface treatment and seal coats.

ASPHALT CEMENT IN ASPHALT CONCRETE MIXTURES

Role in Asphalt Cement in Pavement Performance

Asphalt technologists describe pavement distress by three categories: (1) disintegration, (2) distortion, and (3) fracture.

Examples of each type of distress are shown in the following tabulation:

Disintegration	Distortion	Fracture
Ravelling	Rutting	Low temperature
Pot Holes	Corrugations	Traffic (fatigue)
	Settlement	Shrinkage

A recent literature review and synthesis of information (1) indicates that asphalt related considerations can contribute to the occurrence of each distress type identified above. Table 1 indicates how asphalt consistency, asphalt content and asphalt concrete density (air void content) can affect pavement performance. It should be realized, however, that asphalt related considerations are not the only factors which contribute to the occurrence of distress. Factors such as mixture design, structural design, aggregate properties and adequacy of construction also can significantly influence performance.

Asphalt consistency relates to the hardness and possibly the in-service brittleness of the asphalt; asphalt content influences the asphalt film thicknesses on the aggregate and void content of the asphalt concrete which in turn affects the rate of hardening; and air void content controls the amount of air and water that can permeate the asphalt concrete influencing the rate of oxidation of the asphalt films. Each factor discussed above relates to the durability (rate of field hardening) of the asphalt cement.

Two important conclusions can be drawn from information on Table 1: (1) those characteristics which tend to minimize distortion are opposite to those for disintegration and fracture, (2) of the three asphalt related considerations which affect performance the engineer has the greatest amount of control or influence on asphalt content and asphalt concrete density and the least direct influence on asphalt consistency after field aging.

In spite of the fact that a great deal of research has been accomplished with regard to asphalt properties and pavement performance, there is still a good deal of confusion as regards the critical characteristics of asphalt cement that affect the performance of asphalt concrete. More specifically, it is difficult to translate qualitative relationships into quantitative values. For example, the propensity for ravelling will increase as the asphalt consistency becomes harder; however, there is virtually no quantitative information to identify the critical zones of hardness or consistency.

The conclusions in Reference 1 summarize the current state-of-knowledge as follows:

> "...hardness of the asphalt is the one property most closely associated with performance of pavements. The hardness depends on:
>
> - The initial selection of the proper penetration or viscosity grade of asphalt to accommodate pavement design life and environmental and traffic loading conditions.
> - The temperature-susceptibility characteristics of the asphalt.
> - The susceptibility of the asphalt to hardening during hot-plant mixing and construction of the pavement.
> - The rate of hardening of the asphalt in the pavement in service.
> - Asphalt-aggregate interactions such as adsorption or selective absorption of asphalt components."

Again, it must be noted that these conclusions tend to be of a qualitative nature and of only general help to the engineer in the field. For the most part they represent the traditionally accepted understanding as regards the role of asphalt and selection of asphalt grades for construction.

Asphalt Properties

It is well beyond the scope of this report to delve into any detailed description of asphalt properties. However, in order to facilitate a common understanding of the state-of-the-art, a few comments discussing both physical and chemical properties of asphalt follow. Emphasis will be given to the physical properties since current specification and grade selection are based on physical characteristics. A brief overview of chemical properties will not be a consideration in selecting asphalt type or grade since chemical properties are not included in standard asphalt specifications.

Chemical Properties. A considerable amount of research effort has been directed toward developing a knowledge of the chemical properties of asphalt (2). This overview will indicate the value or objectives of these efforts, and summarize the current status regarding the relationship between properties of the asphalt and pavement performance.

At least two objectives can be identified regarding studies of asphalt chemistry or composition: (1) as an aid in the manufacture (refining) of asphalt, and (2) to correlate the chemical composition of asphalt to the potential performance of the asphalt.

By knowing the chemical composition of asphalts produced from various crudes, it should be possible to make blends which would meet predetermined composition requirements; a "tailor-made" asphalt. In this way more uniformity could be achieved in the production of asphalts.

By knowing the chemical composition of a variety of asphalts (crude sources and refining procedures) it should be possible to establish a correlation with field performance. Proposals have been made by Rostler, et al. (3) to fingerprint asphalts according to their chemical composition. If such a data bank of information could be developed, it is suggested that correlations could be established between the composition and behavior of asphalt in pavements. Rostler states (3) that: "...The unfortunate situation in asphalt chemistry is that a correlation of behavior with composition has not been worked out, and that is the reason for the data bank". He goes on to say "...In every material of construction, including asphalt, the behavior is governed by its chemical composition...". Thus, Rostler and his associates have developed procedures for identifying the chemical composition of asphalt and have made some attempt to correlate composition and behavior.

Asphalt behavior is somewhat confusing in its meaning for the engineer. Rostler generally relates asphalt behavior and pavement performance. However, for the present, behavior is evaluated by laboratory tests in highly controlled environments and conditions e.g., film thickness. For example, artificial aging or laboratory sand-asphalt mixture abrasion tests are used to evaluate behavior. Unfortunately, the correlation of these test results to pavement performance has not been reliably documented by field observations on a large scale. Nevertheless, it is reasonable to assume that the results of such evaluations should have some influence on pavement performance.

No systematic continuation of the data bank proposed and initiated by Rostler has been reported in the literature. The major missing factor is pavement performance as a function of the chemical composition of the asphalt.

The Rostler analysis (4, 5), which has been used in a non-routine manner by the Texas State Department of Highways and Public Transportation (SDHPT), has been designed to identify asphalt according to reactive and non-reactive components. These components are described as asphaltenes, nitrogen bases, first and second acidaffins, and paraffins. Typical values of the more elementary constituents; i.e., carbon, hydrogen, nitrogen, sulphur and oxygen can also be estimated from the composition analysis. However, Rostler and his colleagues believe that efforts to identify the more elementary constituents is more complicated and less meaningful than the component analysis they have developed. Their studies have shown that the durability of an asphalt is controlled by the ratio of the reactive (nitrogen bases and first acidaffins) to non-reactive components (paraffin and second acidaffins). It should be noted that for fingerprinting asphalts, additional measurements of consistency and durability are also required. It is pertinent to note that the chemical composition is primarily applicable to the original asphalt and not to an aged or recovered asphalt, since its primary use is in establishing properties for the refined asphalt.

In order to obtain some correlation with behavior, Rostler has relied on two laboratory tests; specifically: (1) thin film aging of the asphalt, and (2) pellet abrasion (6). Both of these tests are designed to measure the durability of the asphalt after simulated laboratory aging. There is no conclusive evidence of quantitative correlations between the above durability test results and pavement performance. However, the results are believed to be indicative of the durability characteristics of the asphalt in terms of consistency and possibly brittleness.

Corbett and his associates have also studied the chemical properties of asphalt and have attempted to relate these properties to both asphalt behavior and pavement performance (7, 8). These investigators have postulated that the physical properties of asphalt are dependent on the chemical composition of the asphalt.

According to Corbett (7) asphalts can be separated into generic fractions somewhat similar to Rostler; however, different methods for determination are used and hence, the fractions have different compositions from those used by Rostler. Specifically, Corbett separates asphalts into (1) saturates, (2) naphthene-aromatics, (3) polar-aromatics and (4) asphaltenes. The saturates and naphthene-aromatics (penetration 300+) are identified as plasticizers for the harder polar-aromatics and asphaltenes (zero penetration solids).

Corbett (8) attempted to correlate chemical composition with pavement performance on an 18-year-old pavement in Michigan. Performance was limited to ravelling of the asphalt concrete surface. The results were inconclusive as regards the correlation of chemical fractions and ravelling. However, the results did demonstrate accelerated chemical changes at the surface which could account for the ravelling at this level. The methods of analysis proposed by Corbett are currently (1980) being considered as a standard ASTM procedure (9).

Although not entirely new, a considerable amount of interest has been shown recently in inverse gas-liquid chromatography (GLC) as a technique for studying petroleum asphalts. The recent studies are credited to researchers at the Laramie Petroleum Research Center of the U. S. Bureau of Mines. Petersen and his colleagues at the Research Center have published several reports on these techniques (10, 11). Again, these investigators are attempting to characterize asphalts into chemical groups and correlate these properties with behavior and performance.

Of interest to engineers is the suggestion that this technique can be used to identify oxidation characteristics of asphalt and asphalt-aggregate adhesion properties. Limited correlations with field observations and laboratory evaluation suggest that GLC techniques may help resolve the role of chemical composition and pavement performance.

For the most part, research into the chemical properties of asphalt is only of indirect interest to the engineer. He presently cannot use such information in selecting asphalt grades. However, research does indicate that asphalts from different crudes and processed by different methods will have different compositions. The engineer must learn to live with these differences and to compensate through his knowledge of the materials. A knowledge of the chemical composition may be useful in this regard and therefore, inquiries about Rostler parameters, or other chemical characteristics may be useful to the engineer in the long term.

It seems appropriate to summarize this section by referring to results derived from a national survey of 12-year-old pavements, designed to study the role of chemical composition in the field aging of asphalts (12). A few pertinent conclusions reported from this study were as follows:

1. "...good correlation was evident between air voids and (asphalt) hardening, expressed as penetration value of the recovered asphalt. This relationship was evident for all environmental areas..."
2. "...Although (asphalt) hardening was found to be controlled principally by voids content, within defined ranges of void contents field hardening of asphalt was found to be related to Rostler's parameter..."
3. "Relationships sought between mixture and environmental factors and changes in asphalt properties due to field aging were found to be greatly overshadowed by the voids content of the asphalt concrete."

Figure 1 from Reference 12 illustrates results obtained from field samples. All of the asphalts identified on this figure complied with specification requirements for 85-100 penetration asphalt in 1954 and 1956 when the projects were constructed. The test results shown on Figure 1 are representative of 11 to 12 years of in-service aging. It should be noted that the air voids were a function of both construction and traffic. There is no information regarding the as built voids content.

It is pertinent to note from Figure 1 that the point of departure from an almost horizontal line is approximately 7 or 8 percent air voids; i.e., the retained penetration begins to increase as the voids decrease below 8 percent. The aging effects were a minimum for those pavements with air voids below 4 percent after 11 to 12 years of traffic exposure. Thus, the engineer can still use his most direct tools of asphalt content and compaction (density) to control the field aging (hardening) of an asphalt.

Physical Properties. The asphalt physical properties of most interest to the engineer are its rheological properties. Rheological properties for purposes of asphalt identification and specification are usually limited to consistency and ductility. Rheological properties are influenced by the time of loading (shear rate), shear stress and temperature.

The specific rheological characteristics used to categorize different asphalt grades are: penetration (consistency), viscosity (consistency) and ductility. In the purest definition, ductility is only closely connected with rheological properties (13); however, ductility is time and temperature dependent, and for the purposes of this report is considered a rheological property.

The SDHPT specifications are designed to control or influence three important asphalt characteristics; specifically, consistency, durability and temperature susceptibility. Tests for safety and purity are also included in the specifications with specific gravity measurements also commonly made. Tables 2-6 and Figures 2-8 contain data describing asphalt cements currently utilized in Texas.*

Asphalt consistency is the method used to grade asphalts. Consistency is primarily measured in terms of penetration or viscosity at a specified temperature and rate of loading or shear rate. SDHPT specifications refer to kinematic viscosity in units of stokes. Viscosity is sometimes reported as absolute viscosity in units of poise. Absolute viscosity is calculated

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*A list of refinery codes, refinery names and refinery locations can be obtained from the Texas State Department of Highways and Public Transportation, Materials and Tests Division, File D-9, Austin, Texas.

from its kinematic viscosity by multiplying the kinematic viscosity by the density of the asphalt at the test temperature. As a first approximation the multiplier at 140°F would be 0.98 and for 275°F it would be 0.95. From a practical "field" standpoint the appropriate multiplier is usually considered to be 1.00 and thus a correction is not made. Tables 3-6 contain viscosity and penetration data for asphalts used in Texas. Figures 3 and 4 compared the consistency properties of Texas asphalts with those used throughout the United States. The bands or limits shown on these figures are those defined by Puzinauskas (14) and represent limits of over 100 asphalts obtained and tested during the period 1950 to 1977. With the exception of asphalts produced from refinery number 5 (Figure 4), all asphalts used in Texas are within the range of consistency properties for asphalts used throughout the United States.

Durability of asphalt refers to the ability of asphaltic materials to retain their original characteristics or properties after aging and exposure to the environment. Some investigators point out that many asphalts have good durability (moderate change in consistency) but because of poor mixture design and/or construction, the pavement is not durable.

At the present time there is no generally accepted test which is reliably indicative of asphalt hardening beyond the construction phase. Some studies in Texas have been reported by Benson (15); however, no general relationships to long-term aging have evolved from these investigations. Field studies have shown that accelerated aging (hardening) can continue for up to 3 to 5 years after construction. Beyond this time period, aging continues but at a relatively slow rate.

Texas specifications limit the amount of hardening in the laboratory thin film oven test to 3.75 times the original (unaged) viscosity (Table 7)

(16). The standard AASHTO (M226) and ASTM specifications (D3381) allow an increase equal to four or five times the original viscosity. Thus, Texas is restricting the hardening of the asphalt to a greater degree than is presently required by standard specifications.

Figure 5 illustrates that this more restrictive Texas specification is indeed effective as the asphalts used in Texas are plotted on the lower portion of this figure. The bands on this figure represent typical asphalts used throughout the United States. Asphalts produced from refineries 5, 6, 9 and 11 have relatively low hardening on exposure to the thin film oven test (TFOT) while asphalt from refineries 3, 4, 15 and 17 have a relatively high degree of hardening.

Figure 6 indicates that if hardening before and after TFOT is evaluated by the penetration test rather than the viscosity test (Figure 5), the asphalts used in Texas can be expected to harden to about the same degree as asphalts historically produced throughout the United States. Some grades of asphalt from refinery 4 hardened more than typical asphalts produced throughout the United States.

Viscosity ratios of laboratory aged asphalts used in Texas are shown on Tables 3-6. The range of values is between 1.50 and 2.7. Thus, under normal hot mixing operations the engineer could expect the viscosity of the asphalt to increase from 1.5 to 2.7 times its original value, i.e., an AC-10 asphalt cement after hot mixing would have viscosity typically between 1500 and 2700 stokes. Thus, the original AC-10 asphalt becomes an AC-20 asphalt as it is placed on the roadway.

As indicated above hardening continues after the hot mix process. Traxler (17) has reported that asphalts have been extracted and recovered from Texas with viscosities 14 times greater than the original asphalt.

Other studies conducted at the Texas Transportation Institute have reported viscosities 25 times greater.

Temperature susceptibility refers to the rate of change in asphalt consistency with a change in temperature. There are a number of procedures for evaluating temperature susceptibility; the most commonly used indicator is the so-called P.I. value or penetration index. McLeod (15) has developed a procedure for evaluating the penetration index of asphalts based on measurements of the penetration at 25°C (77°F) and viscosity (centistokes) at 135°C (275°F). The P.I. or Pen-Vis Number (PVN) of most paving grade asphalts will be between 0 and -1.5 according to McLeod (18). Temperature susceptibility increases as the PVN decreases; i.e., an asphalt with a -1.5 PVN is more temperature susceptible than an asphalt with a -0.5 PVN.

Based on recently obtained laboratory test data, asphalts currently in use in Texas range in PVN from +0.9 to -1.2 (Table 2). The median PVN for asphalts supplied in Texas is approximately -0.4 which would be considered fairly typical of most asphalts currently produced in the United States. The +0.9 PVN from one refinery has a very low temperature susceptibility and should exhibit a high tolerance to low temperature environments without exhibiting transverse cracking; i.e., minimum probability of cracking at -20°F. Asphalts with low temperature susceptibility would require relatively high temperatures in order to reach a mixing viscosity. Table 2 summarizes typical asphalt temperature susceptibility for various refineries in Texas according to their PVN values.

Ductility is a controversial characteristic of asphalt. Despite the controversy, nearly all asphalt specifications include some requirement for ductility. Correlations have been reported between ductility and field performance.

Halstead (19) has reported on studies relating ductility to performance. He concludes that the decrease in ductility with aging is an important secondary factor to be considered in the performance of asphalt pavements. Specific findings indicate that a "critical" ductility-penetration relationship may exist for in-service asphalts. Suggested values are summarized in Table 8. It is pertinent to note that some of the asphalts in the pavements included in the Halstead studies which performed satisfactorily did not meet the "critical" relationship; however, all of the pavements with asphalts meeting the relationship did perform satisfactorily. Krchma has recently reviewed Halstead's data and has suggested a revised set of criteria as shown on Table 8 (20).

Recent reports from the California Department of Transportation (Caltrans) (21) generally confirm the findings of Halstead. Specifically, Caltrans reports that pavements with recovered penetrations of 17 (average) and ductility of 20 exhibited distress (10 percent cracking) in 6 to 8 years. Pavements with penetrations of 20 and ductility of 70 after 6 years of service survived to 13 to 15 years before exhibiting 10 percent cracking. The objections to using ductility as an indicator of asphalt properties centers on two items: (1) the difficulty in obtaining reproducible measurements, particularly on aged specimens when tested at low temperatures and (2) the availability of more fundamental properties, such as stiffness, which can be used in lieu of ductility. Alternative ductility tests are being researched at the present time by the Utah DOT (force-ductility) (22) but have not as yet progressed to the specification stage.

Flash point and solubility are tests included in specifications which play very little role in grade selection and have no clearly defined association with performance. However, asphalt cements with low flash points may show abnormally high hot mix hardening and age hardening. This property may be reflected in a high increase in viscosity after the thin film oven test. Flash point is generally considered a safety requirement to protect against fire hazards in handling asphalt and manufacturing asphalt concrete.

The solubility test determines the bitumen content in the asphalt cement. It can be considered as a control of the purity of the asphalt by minimizing the amount of foreign substances. Excessive amounts of fine insoluble matter may also affect performance.

The spot test is also somewhat controversial but also appears in most asphalt specifications including the current Texas specifications. Some technologists believe that the spot test is associated with pavement performance. It is basically a control to disclose overheating of the asphalt in the manufacturing process. This is a "go" or "no-go" type of test which the asphalts either pass or do not pass; there is no choice or difference as a function of the grade of asphalt.

Changing Asphalt Properties: 1950-1980

There is a continuing debate regarding the quality of asphalts currently being produced and those which have been produced in previous years. For the most part, field personnel believe that asphalts as produced today are of inferior quality to those that were available 10 or 15 years ago. The most common complaint is that asphalts of today do not possess the same adhesive properties, that viscosity-graded asphalts age more rapidly than the previously penetration graded asphalts, and that they behave differently with changing temperature. Often, the complaints are made that refiners are removing desirable components from asphalts which has led to the production of inferior asphalts with inferior performance records. It will be appropriate to comment somewhat on this concern based on recent studies by The Asphalt Institute.

The Asphalt Institute Study. At the 1979 annual meeting of the Association of Asphalt Paving Technologists, Puzinauskas (14) of The Asphalt Institute reported on an investigation of properties of asphalt cement. The investigation, unfortunately, was limited to comparisions over time of physical properties and does not deal with chemical composition. The investigation is also limited to laboratory simulation of aging. Even so, the investigation was very extensive with regard to the physical properties of asphalt.

Current studies sponsored by the Federal Highway Administration (FHWA) will expand on information reported by The Institute to include chemical composition and performance. However, it will be several years before the FHWA information becomes available in a complete form (23).

The Asphalt Institute study concentrated on measurements of asphalt viscosity at different temperatures both before and after artificial aging in the laboratory. It should be remembered that the artificial aging is primarily indicative of changes which occur in the hot mixing process, and not long-term hardening.

Sixty-eight asphalt cements representative of 1977 production were selected for evaluation of currently produced asphalts. Properties of asphalt production during 1960 and from 1965 to 1973 (pre-embargo) were obtained from similar studies made by The Asphalt Institute and Bureau of Public Roads (FHWA) during the respective time periods. The asphalts were selected to include all of the ASTM gradings and were believed to be representative of all major crude oil sources both domestic and foreign. Also, all major currently in-use manufacturing processes were represented by this large group of asphalt cements. For anyone interested in the history of asphalt properties, the report by Puzinauskas (14) should be reviewed in detail.

To some, the results of the investigation will be disappointing in that the results do not confirm what is generally thought to be the case as regards differences in asphalt properties since 1960. The following conclusions were reported by Puzinauskas and may be of value to a better understanding of the problem:

(1) Asphalts produced today do not differ substantially from those produced in the past. This applies not only to the conventional properties utilized in materials specifications, but also to measurements such as temperature-susceptibility, heat effects, and shear sensitivity.

(2) Asphalts, within a given grade, do differ substantially in their properties. For example, the temperature susceptibility of asphalts can be significantly different within a given grade. However, the magnitude of this difference appears to be similar for asphalts manufactured during different time periods.

(3) Both the source of parent oil and the method of manufacture affect the physical properties of asphalt cements. However, because of the wide variation in manufacturing conditions, it is difficult to single out the separate effects of these two factors.

(4) The response of asphalt to heating is highly variable. Generally, viscosity at low temperatures is affected by heating more than viscosity at high temperatures. In most cases, heating increases the temperature-susceptibility of asphalt. Also, the agreement between heating effects as assessed by viscosity and penetration tests is poor.

(5) The low-temperature viscosities of asphalt cement were found to vary. This range increases with decreasing temperatures. Generally, poor correlations was registered between properties such as viscosity, penetration, or ductility. Furthermore, measurements at high or moderate temperatures cannot be used to predict behavior of asphalt at subfreezing temperatures.

(6) In paving mixtures, at temperatures of pavement use, the asphalt is mixed in thin films with a variety of mineral substances. With fillers it forms binders varying greatly in properties from the original in-bulk asphalt. The measurement of paving mixture properties, rather than the properties of the binder, appears to be a more rational approach.

A summary of these conclusions pertinent to this report would be as follows:

(1) Asphalts, within a given viscosity grade, differ substantially in their properties.

(2) Both the source of the crude oil and method of manufacture affect the physical properties of asphalt cements.

(3) The response (hardening) of asphalts from heating is variable.

(4) The low temperature viscosities of unaged asphalt cements within a given grade were found to vary over a wide range of values.

(5) In paving mixtures the properties of binder (asphalt and filler) are influenced by the amount and type of mineral filler.

Reference to the influence of mineral fillers on properties of the binder in a paving mixture would seem highly significant and suggests a need for careful evaluation of mixture properties as well as the asphalt properties.

In drawing his conclusions Puzinauskas is considering overall changes in asphalt properties and does not evaluate "site specific" situations. That is, overall (nationwide) the physical properties of asphalts have not changed; however, at specific refineries the physical properties of asphalts have changed (24).

Pennsylvania State University Study. Anderson and Dukatz (23) conducted studies similar to those reported by Puzinauskas (14). These investigators did include some consideration of chemical composition as generally determined by Rostler parameters or adaptations of these parameters as suggested by Gotolski. Anderson et al., concluded that there are statistically significant differences in the chemical and physical properties of the asphalts sampled and tested over the time period 1950-1980. The differences were reported to be associated with temperature susceptibility and chemical composition parameters. The effect of heating (aging) did not appear to be of concern based on results from this investigation.

Examination of the Anderson data indicates that the mean temperature susceptibility (PVN) increased from -0.35 to -0.71 from 1950 to 1979, respectively. While this may be statistically significant, it is still well within the range of values for asphalts which have been produced and used in the United States during this period. For example, 19 percent of the 1950 asphalt samples had a temperature susceptibility (PVN) between -0.6 and -0.9.

It is also worth noting that when temperature susceptibility is calculated by alternative procedures there is no indicated change in this particular property during the period under examination. This would suggest that measurement procedures are influencing indications of changes in asphalt properties.

Anderson, et al., (20) state that correlations between asphalt properties and performance were not available; hence, performance indicators such as temperature susceptibility were used as a proxy for performance. The results from Anderson suggest that temperature susceptibility and chemical composition may be changing with time; however, the changes, if they are occurring, remain within the general range of values associated with asphalt produced during the period from 1950 to 1980.

<u>Texas A&M University Study</u>. Button, et al., gathered and analyzed data on the historic variability of the temperature susceptibility of asphalt cements from throughout the United States under sponsorship of NCHRP (24). Data collected from specific refinery sources indicated that the physical properties of asphalt cements have changed significantly with time from an engineering standpoint while asphalts from other refineries show no statistically significant change in their physical properties. The authors conclude that engineers in selected areas of the United States will be expected to utilize asphalt cements whose properties will change with time. In all probability the range of asphalt cement properties from a given refinery over a period of time will be no greater than the range of asphalt cement properties currently existing among refineries in the United States.

Since a wide range of asphalt cements are currently successfully used in the United States, it is reasonable to assume that technology exists which will allow the engineer to successfully make use of a changing asphalt cement from a given refinery.

Summary. The results obtained by The Asphalt Institute (14), Pennsylvania State University (23) and the Texas Transportation Institute (24) appear to be somewhat contradictory. However, if it is concluded that changes in asphalt properties are occurring, as suggested by Anderson, these changes are not outside of the limits of asphalts produced during the 1950 to 1980 period. Physical properties of asphalts from specific refineries have changed (24); however, the degree of change may not be to the degree necessary to cause premature distress. It does not appear that changes in asphalt that relate to performance can be identified by the traditional tests used to measure asphalt characteristics.

ASPHALT SPECIFICATIONS

In the previous portions of this report a general review has been provided as regards (1) the role of asphalt to pavement performance, (2) the chemical and physical properties of asphalt and (3) historic changes in asphalt properties. In this section an effort will be made to relate the general properties of asphalt to the asphalt specifications used by the State Department of Highways and Public Transportation (Table 7).

Consistency and Temperature Susceptibility

Grading by viscosity intervals is provided by the five grades; i.e., AC-3, 5, 10, 20, and 40. The most commonly used grades for HMAC are 10 and 20, with grades 3, 5 and 40 reserved for special situations or types of construction.

The viscosity limits at $140^{o}F$ for each grading band; i.e., AC-5, 10 and 20, can be thought of as a gate through which the asphalt consistency property must pass in order to comply with the specifications. Thus, at $140^{o}F$, both a maximum and minimum viscosity are stipulated by the specifications. The viscosities at $275^{o}F$ and $77^{o}F$ are controlled by a maximum value at $77^{o}F$ or a minimum value at $275^{o}F$.

Figure 2 illustrates how asphalt consistency is controlled for an AC-5 grade of asphalt. In order to plot consistency on this ASTM Standard Viscosity-Temperature Chart for Asphalt (ASTM D 2493), it is necessary to convert kinematic viscosity in stokes to poises by multiplying by the appropriate specific gravity and to convert penetration to viscosity using an empirical relationship reported by Pfieffer (13).*

It can be noted on Figure 2 that the viscosity of the asphalts from refineries 5 and 28 are very similar at $140^{o}F$ but diverge in value at temperatures above or below $140^{o}F$. Also, there may be a change in the temperature susceptibility between $77^{o}F$ and $275^{o}F$ since asphalts "B" and "C" have similar viscosities at $77^{o}F$ and vary considerably at $275^{o}F$.

The line represented by asphalt "A" is a hypothetical indication of a limiting value for temperature susceptibility. A similar relationship is also applicable to the AC-10 and 20 grades. Specifically, the maximum temperature susceptibility is represented by a PVN of -1.5. It can be observed from Figure 2 that there is no constraint on how low the temperature susceptibility can be; technically, a horizontal line is possible but clearly not practical.

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*$n \text{ (poises)} = \frac{1.58 \times 10^{10}}{\text{Pen}^{2.16}}$

Interpretations available from Figure 2 are as follows:

1. The Asphalt Institute (25) recommends that the mixing temperature for asphalt should be approximately 1.8 ± 0.20 stokes. Using this recommendation as a guide, the mixing temperature for asphalt "A" would be 265°F, for asphalt "B" it would be 285°F, and for "C" a high of 315°F. Thus, for a given asphalt grade a difference of 50°F is possible for the mixing temperature.
2. The asphalt viscosity at low temperatures will also be different for the three asphalts. For example, at 30°F the viscosities would be: "A" = 5×10^8 poise, "B"= 1.7×10^8 poise and "C" = 0.8×10^8 poise.

When interpreting viscosity information from ASTM Chart D 2493 (Figure 2) it must be recognized that the ordinate scale is plotted as the log log of viscosity. The reason for using this scale is that it produces a straight line, or nearly so, relationship with temperature. Hence, small scaler differences at high values of viscosity actually represent large differences in the consistency value of asphalt.

Similar interpretations will be found for asphalt grades 10 and 20. Some care must be taken in interpreting the properties of in-place asphalts due to hardening associated with mixing and aging. Nevertheless, the temperature sensitivity of the bulk unaged asphalt is an indicator of the same tendencies after aging. Studies by Puzinauskas (14) indicate that the temperature-susceptibility increases slightly with aging although there is no unique relationship; some asphalts decrease in temperature susceptibility and some do not change. Thus, it is reasonable to assume, for design purposes, that temperature susceptibility characteristics before and after aging are similar.

Durability

The durability of asphalt is a measure of the change in consistency properties usually measured in terms of time or aging. Asphalts harden (lower penetration), become more viscous with time: hence, durability is often referenced to the consistency properties of the original asphalt. Durability can also be expressed in absolute values of viscosity or ductility as in the case of the SDHPT Standard Specifications (1972) (16).

The mechanisms contributing to asphalt hardening are many and varied. Traxler (26) has described fifteen factors which can influence the rate of hardening of asphalt, ranging from oxidation to microbiological deterioration. Obviously, this is a very complicated subject and no detailed discussion is planned. However, it is worth noting that time, heat and oxygen are the main ingredients necessary to cause a change in consistency through the various mechanisms described by Traxler.

Texas specifications control asphalt durability on the basis of tests made on the residue from the thin film oven test (Tex-510-C). According to notes in the test method "...The thin-film test is used in conjunction with the absolute viscosity test at $140^{o}F$ and the ductility test to detect the hardening effects of asphalt binder when subjected to high temperature and exposure to air. The test provides a relative measure of the resistance of asphalt to hardening during the mixing, processing and service conditions".

The current SDHPT specifications limit the increase in asphalt viscosity after thin film aging to a maximum of 3.75 that of the original asphalt. Thus, the maximum increase in viscosity which would be expected after construction would be 3.75 times that of the original viscosity. Most Texas supplied asphalt will have a 1.5 to 2.7 increase in viscosity by thin film aging (Tables 3-6).

Without apologizing for the thin film oven test, it is pertinent to note that laboratory aging tests should not be considered as reliable indicators of long term aging. Kemp (27) of Caltrans summarizes an investigation of both physical and chemical laboratory tests used to predict long term changes in asphalt consistency based on field tests in eight locations in California. Kemp concludes with the following statement, "In comparing the correlation coefficients by different statistical methods, we see that none of the correlation values will sufficiently indicate that any of the laboratory test procedures could be depended upon to predict adequately field weathering durability....In regard to the correlation coefficients determined on the 50-month data, we see that the best correlation is by the percent of original voids no matter what statistical program is used."

Kemp's studies showed that asphalts increased in viscosity, at 77°F, by a factor of 2.24 to 16.1 for mixes with acceptable air voids and a factor of 49 for a mix with high voids. Only the mix with the high air voids was exhibiting excessive block or alligator cracking after 50 months of service. All sections had low deflections and were considered structurally adequate.

Based on field studies by Sisko (28) a critical asphalt viscosity to minimize cracking in asphalt concrete would be 15,000 poises. Thus, the aging factor needs only to be limited to 7.5 for an AC-20; i.e., ratio of 15,000 poises for aged asphalt to 2,000 poises for original asphalt. If it is assumed that the asphalt consistency increases by a factor of 2 during mixing and placing the field aging needs to be limited to a factor of 5.5. This factor was exceeded in 50 percent of the test projects reported by Kemp. If an AC-10 were selected initially, the critical viscosity would be less likely to occur under normal conditions.

Some engineers question if the choice of a softer asphalt initially will actually have a significant effect on the asphalt viscosity after 10 years or more of in-service aging. There is little quantitative information to prove or disprove such a contention under controlled conditions. Data summarized by Kemp (27) includes a project in Blythe, California (hot-dry climate). On this project both a 200-300 penetration and 85-100 penetration asphalt were used. After 25 months the viscosity of the 200-300 asphalt was 4.78 megapoises at 77°F while the 85-100 asphalt had a viscosity of 29.2 megapoises at 77°F.

Ductility requirements in specifications for asphalts have been the subject of debate among asphalt technologists since its introduction in the early part of the century. Welborn, et al., (29) indicate that some technologists are of the opinion that ductility, under the present standard test method, is of little value as an indicator of asphalt quality. Others believe that the ductile properties of asphalt give an asphalt pavement its quality of flexibility - the ability to conform to moderate deflections or changes in supporting layers without permanent cracking or disintegration. Ductility could also provide some accommodation for volume changes due to temperature cycling. Some believe that ductility is related to stickiness or ability to adhere to aggregate and other surfaces.

Regardless of the merits, ductility of recovered asphalts has been correlated with performance by some investigators and is included in the Texas specifications. Asphalts supplied in Texas will easily meet the SDHPT specification requirements (Table 7).

Safety

The Flash Point Test is included as a traditional safety test. It also influences the character of the lighter components in the asphalts as regards their volatility and some investigators believe there is an association with durability (30). Hveem (30) also indicates the flash point"... may have value by insuring more uniform production from various sources".

Composition

The Solubility and Spot Tests have been discussed previously and play no role in the selection of the asphalt grade. These tests are indicators of the purity and homogeneity of the asphalt.

Summary

A great deal of information is available concerning both the chemical and physical properties of asphalt. Engineers responsible for selecting asphalts for specific projects should become familiar with the properties of asphalts in general, and should have a detailed knowledge of those asphalts which are likely to be used on projects under their direct supervision.

The selection of the asphalt grade will depend on such factors as traffic, temperature and HMAC thickness. Selection will also be based on local experience and performance observations.

It should be remembered that the state-of-the-art knowledge of asphalt properties (bulk) and pavement performance is very limited. For example, asphalt durability is based on laboratory simulation and no tests are available which can reliably predict the long-term aging properties of asphalt binders. One of the major difficulties with such predictions is the dominant influence of asphalt content and air voids in the compacted in-service asphalt concrete.

Finally, selecting the grade of asphalt to be used, the engineer is limited to those asphalts which are produced under prevailing standard specifications. There is a prevailing belief that such specifications do not adequately describe a quality asphalt or even a uniform asphalt. However, research has not yet resolved this problem satisfactorily within economic constraints which are placed on both the user and the producer. Therefore, for the present, the selection must be made on the basis of the potential performance of the asphalt assuming that proper mix designs will be developed and that construction will help compensate for certain deficiencies which may exist in the asphalt.

RECOMMENDATIONS FOR SELECTION OF ASPHALT GRADE FOR ASPHALT CONCRETE

The primary considerations in selecting an asphalt grade are (1) temperature regime, (2) structural design, i.e., thickness of asphalt concrete and (3) traffic.

Temperature

Figure 9 is a chart developed by McLeod (18) for selecting grades of asphalt cement to avoid low-temperature transverse pavement cracking based on the expected minimum temperature at the surface of the asphalt concrete. The following relationship developed by Christison and Anderson (31) can be used as a first approximation of pavement surface temperature:

$$T_s = 8.0 + 0.8\, T_{MA}$$

Where: T_s = pavement surface temperature

T_{MA} = minimum daily air temperature

Figure 7 illustrates how the relationships in Figure 9 can be used for evaluating typical AC-5 asphalts producted in Texas. Of the seven asphalts shown, six should perform satisfactorily at -10^{O}F without low temperature transverse cracking. If the remaining asphalts were to be supplied in an area where minimum pavement temperature was expected to reach -10°F or less, it would be advisable to consider a change to an AC-3 grade, providing all mix design criteria can be met. All ten asphalts would be acceptable at pavement temperatures of 0°F and 10°F.

Figure 8 is a similar interpretation for a set of typical AC-10 asphalts. Six out of twelve would be satisfactory for minimum temperatures of +10°F, five may not; and a change to AC-5 would be in order for these five asphalts.

If low temperature transverse cracking is a problem in the area for which a particular project is being designed, Table 9 can be used as a guide. Figure 10 shows minimum temperature regimes for Texas based on data recorded between 1951 and 1979.

Thickness of Asphalt Concrete

In situations where very high traffic volumes and weights are expected, and asphalt concrete thicknesses exceed 4 inches, the softer grades should be considered for use in the wearing surface with a harder grade in the underlying layers. This would offset concern relative to potential rutting in the asphalt concrete.

Table 10 from Reference 32 provides a set of recommendations for selection of asphalt grades which is an effort to combine thickness of asphalt concrete and temperature. The AC-40 grade is recommended for the thicker asphalt layers in hot climates to reduce the susceptibility for rutting and to increase the pavement stiffness and reduce the tendency for fatigue cracking. In this type of design the objective is no longer to design a flexible pavement, but to approach a quasi-rigid type design which can accommodate long time movements in the supporting pavement layers and foundation materials.

Traffic

In general, as traffic increases and the thickness of the asphalt concrete increases, it is desirable to use asphalts of a higher consistency. The use of soft grades of asphalt (AC-5) for projects with high traffic volumes and truck weights may be questionable with regard to potential rutting. In such situations, and depending on local experience, and if AC-5 is stipulated, it may be necessary to increase the percent of crushed aggregate and/or mineral filler in comparison with material requirements. Each requirement would be in addition to the usual stability requirements included in the standard specifications for asphalt concrete.

Selection of Asphalt Grade - Examples

In order to illustrate the process recommended for asphalt grade selection several examples for hypothetical cases in various parts of Texas will be presented. The general approach will be as follows: (1) start with an initial selection, (2) check to determine if lower (softer) grade should be used to accommodate minimum temperature possibilities, and (3) if low temperature is not a problem, determine if a higher (harder) grade should be used to minimize rutting and bleeding problems.

Example No. 1 - District 1, Lamar County. The following information is available for asphalt grade selection:

(1) Minimum expected air temperature: -5°F (Figure 10)

(2) Thickness of asphalt concrete: 3 inches

(3) Traffic: Average daily truck traffic in design lane; less than 100.

(4) Probable source of asphalt: Refinery Code 26.

Based on the minimum air temperature of -5°F it is estimated that the minimum pavement (surface) temperature will be 4°F. [$T_s = 8.0 + 0.8\ (-5)$].

As a first iteration select an AC-10 grade of asphalt.

An AC-10 from Refinery 26 is estimated to be satisfactory for minimum temperatures of about 3°F (Figure 8); therefore, due to the marginal conditions some consideration should be given to the use of a softer grade of asphalt. Before a decision is made, an examination of other considerations should be completed.

The AC-5 asphalt from Refinery 26 should be satisfactory at pavement temperatures less than -10°F (Figure 7). The maximum air temperature in this area is 112°F (Figure 11) resulting in a pavement temperature of 160°F, (Table 11) (29). Although no specific criteria are available, this relatively high temperature would indicate that grades of asphalt softer than an AC-10 could lead to rutting or bleeding under heavy traffic. Since the project under consideration will be subjected to relatively light traffic an AC-5 asphalt should perform satisfactorily.

On the basis of the above considerations, the AC-5 grade of asphalt is recommended. Special care will be necessary in designing the asphalt concrete to assure adequate stability. Finally, some judgement is necessary in making the final selection. Specifically, comparisons with past experience will be important. If AC-5 asphalts have consistently been a problem with rutting or bleeding, more emphasis should be given to the mix design. If AC-10 asphalts have not posed a problem to performance, it would be worth reconsidering the original recommendation. Also, updated physical property tests on the asphalt should be made to check the need for a lower grade.

Example No. 2 - District 4, Carson County

The following information is available for asphalt grade selection:

1) Minimum expected air temperature: -15F (Figure 10)

2) Thickness of HMAC: 3 inches

3) Traffic: Average daily truck traffic in design lane; less than 100.

4) Probable source of asphalt: Refinery Code 5

Based on the minimum air temperature of -15 F it is estimated that the minimum pavement (surface) temperature will be -4 F. [$T_s = 8.0+0.8(-15)$]

As a first iteration select an AC-10 grade of asphalt.

An AC-10 from Refinery 5 should provide satisfactory service at -15°F (Figure B) therefore, a softer grade is not necessary. Because of the low temperature susceptibility of the asphalt from this refinery, consideration could be given to the use of an AC-20 in this instance.

The maximum air temperatures in this area are 110°F (Figure 11) traffic is relatively low. An AC-10 is recommended in this case. If the traffic had been high; e.g. greater than 1000 average daily trucks in design lane, an AC-20 would be recommended. If an AC-20 is selected, it will be critical to achieve low in-situ air voids in the compacted HMAC in order to avoid excessive hardening.

Example No. 3 - District 20, Jefferson County

The following information is available for asphalt grade selection:

1) Minimum expected air temperature: +15°F (Figure 10)

2) Thickness of HMAC: 3 to 6 inches

3) Traffic: Average daily truck traffic in design; approximately 500

4) Probable source of asphalt: Refineries Code 06 or 12

Based on the minimum air temperature of +15°F it is estimated that the minimum pavement (surface) temperature will be +20°F [Ts=8.0+0.8(15)]

As a first iteration select an AC-10 grade of asphalt.

An AC-10 from Refinery 12 should provide satisfactory service at 0°F and should be satisfactory (Figure 8). However, asphalt from Refinery 06 will be marginal at +20°F and consideration should be given to using an AC-5.

The maximum air temperature for this area is approximately 105 F (Figure 11) resulting in pavement temperatures of 150 F (Table 11).

An AC-10 grade of asphalt is recommended for Refinery 12; if the asphalt comes from Refinery 06, consideration should be given to using an AC-5 if problems of low temperature cracking have been observed on pavements of comparable design. Adequate stability and resistance to rutting should be obtained in all asphalt concrete mixtures which utilize with those softer asphalt cements.

Example No. 4 District 5, Lubbock County

The following information is available for asphalt grade selection:

1) Minimum expected air temperature: -10 F (Figure 10)
2) Thickness of HMAC: greater than .6 inches
3) Traffic: Average daily truck traffic in design lane greater than 1000.
4) Probable source of asphalt: Refineries Code 4

Based on the minimum air temperature of -10°F it is estimated that the minimum pavement (surface) temperature will be 0°F. [Ts=8.0+0.8(-10)]

As a first iteration select an AC-10 grade of asphalt.

An AC-10 from Refinery 4 should provide satisfactory service above a temperature of +18 F (Figure 8). An AC-10 from Refinery 5 should provide satisfactory service at -12 F or lower (Figure 8)

If asphalt from refinery 4 is to be used, consideration should be given to the use of special fillers; e.g. crushed limestone or hydrated lime, in order to stiffen the asphalt concrete against shoving and rutting. Some reduction in asphalt content in the lower layers should be considered providing air voids criteria can be met. This may mean adjustments in the gradation to produce a dense graded mixture.

The use of an AC-10 or AC-20 below the wearing surface would be another alternative in the event that an AC-5 asphalt is used in the asphalt concrete surface course. This alternative must be considered experimental since there is limited field data to justify the benefits.

In any event if the AC-5 were to be selected, considerable care would be required in the overall design (stability, gradation, and voids) of the asphalt concrete mixture.

If asphalt from refinery 5 is used, consideration should be given to specifying an AC-20. The PVN of this asphalt is +0.7 (Table 2). Based on relationships shown in Figure 9, an AC-20 from this source should be satisfactory at 0 F (penetration at 77 F of 80 and viscosity at 275 F of 627 centipoises (Table 6)). The only concern in using this grade would be the relative high temperature required to achieve adequate mixing and compaction during construction.

Summary

A great deal of research has been completed with regard to the properties of asphalt. In spite of the amount of research there is still a considerable amount of confusion regarding the desirable properties to be used in defining a "quality" asphalt. Some technologists openly question the adequacy of current asphalt specifications to measure the relative quality of different materials.

In addition to the relevancy of the asphalt properties used in the specifications is the question of uniformity of materials supplied under current specifications; i.e. differences between suppliers for the same asphalt grade.

There are good and valid reasons which can be developed to explain the problems now facing the asphalt producer and the user which have led to a less than perfect set of specifications. All of these explanations are of little help to the engineer responsible for recommending or selecting a specific grade for a specific project. The engineer can only select from those asphalts available under current specifications.

Some background information and guidelines for asphalt cement grade selection for asphalt concrete have been provided in the previous sections of this report. In the final analysis the engineer must weigh this information against local experience in making a recommendation. The principal considerations are (1) a knowledge of asphalts being supplied in the area and (2) a knowledge of performance problems in the area.

One specific example of performance and asphalt grade is the occurrence of low temperature cracking. If this is a problem in a particular area, there is very little the engineer can do except select a soft asphalt; e. g. AC-5, depending on temperature susceptibility (Figures 7,8,9, and 10).

It is pertinent at this stage to note that asphalt properties are only one of several factors which contribute to the satisfactory or unsatisfactory performance of asphalt type pavements. Field data have consistently demonstrated that such factors as asphalt content and the density of the asphalt concrete combined can play an even more important role than asphalt properties. Thus the engineer can significantly offset any problems with the asphalt by concentrating on mix design considerations and construction procedures.

RECOMMENDATIONS FOR SELECTION OF ASPHALT GRADE FOR CHIP SEAL COATS

The type and grade of asphalt selected for a particular seal coat project should have the following characteristics:

1. Fluid enough at the temperature of spraying to allow uniform application.

2. Fluid enough at the time the cover aggregate is applied to develop rapid wetting and fast initial adhesion between the binder and the aggregates as well as to the underlying road surface.

3. Viscous or hard enough to retain the cover stone when the surface is opened to traffic.

4. Viscous or hard enough in hot weather that the aggregates will not be whipped off and the road surface will not distort.

5. Fluid or soft enough (not brittle) in cold weather that the aggregate will not be whipped off and the road surface will not crack.

6. Resistant to the effects of sunlight and air (prevent excessive hardening due to aging of the asphalt)

7. Resistant to the combined action of water and traffic such that stripping of the aggregate will not occur.

Asphalt cements, emulsified asphalts and cut-back asphalts, as specified by Item 300 of the Texas State Department of Highways and Public Transportation Standard Specification (16) are utilized for seal coats. Each of the three types of asphalt products has its own virtues and problems which should be recognized when a selection is made.

Table 12 lists advantages and potential problems associated with these asphalt types (33).

Many grades of the three types of asphalt are available, but only a few are normally used for seal coats. These are shown below.

Asphalt Type	Identification Under Item 300.2 SDHPT Standard Specifications
Asphalt Cement	Viscosity Grades AC-5, AC-10
Asphalt Emulsion (Anionic)	EA-HVRS, EA-HVRS-90
Asphalt Emulsion (Cationic)	ER-CRS-2, EA-CRS-2h
Cut-Back Asphalt*	RC-2, RC-250, RC-3, RC-4, RC-5, MC-800, MC-3000

Recommendations for selection of asphalt type and grade based on criteria for the construction environment and expected surface exposure conditions in various parts of the state are given in Tables 13 and 14 and supported by Figure 12. These should be considered to be guidelines rather than firm recommendations. Modifications should be made (as necessary), to fit specific local conditions.

Selection of the proper type and grade of asphalt also depends on the type of cover aggregate to be spread on the asphalt layer. Guidance for making a selection on the basis of aggregate type is given in Table 16, and Figure 13. Application of Figure 13 for classification of natural gravels may pose some problems since aggregates often consist of a mixture of a number of rock types. However, usually aggregates can be classified from a knowledge of the local geology, and petrographic and/or visual examination. For example, most natural gravels taken

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*Energy conservation and air quality problems will usually rule out the use of cut-back asphalts except for emergency repair during the winter months.

from the Brazos River terraces have a relatively high silica content and are therefore mostly hydrophilic. When there is doubt, personnel of the Texas State Department of Highways and Public Transportation Materials and Test Division (D-9) should be consulted.

The final selection of the type and grade of asphalt to be used should be made on the basis of recommendations presented on Tables 13, 14. 15, and Figure 13. For example, if a chip seal is to be applied during the summer in a Zone IA climate and trap-rock aggregate is used the following types of asphalts would be expected to give satisfactory performance; AC-5, AC-10, EA-CRS-2, and EA-CRS-2h. If a chip seal is to be applied in the spring in a Zone IIB climate and a lightweight aggregate is used, the best choice is the cationic asphalt emulsion EA-CRS-2. An RC-4 or RC-5 could be used on low traffic volume facilities.

Selecting asphalts for late season construction present special problems as the cover stone is normally not embeded to the desired level prior to the occurrence of cold nights. With shallow embedment depths and a somewhat brittle asphalt; raveling at the centerline, between the wheel path and perhaps in the wheel path will likely occur. If construction must occur late in the summer or early in the fall, the grade of asphalt cement to be selected should be one grade softer than normally used (i.e., AC-5 rather than AC-10 and AC-3 rather than AC-5). Temperature susceptibility should be evaluated prior to final selection of the asphalt for the project.

Summary

The information provided herein should be useful in selecting asphalt for seal coats and surface treatments.

It is emphasized that in order to reduce the risk of unsatisfactory construction, a great deal of attention will need to be given to the rate of application of the asphalt material and to the logistics of application. Probably no other road construction activity is so dependent on the skill and management of the on-site personnel, materials and equipment. Careful planning is essential and one major item in the planning process is the selection of an appropriate asphaltic material according to the procedures described herein. Reference 33 contains details associated with proper seal coat construction in manual form.

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Table 1. Desirable Characteristics Associated with HMAC Performance

	HMAC Properties			
Distress Type	Asphalt Content	HMAC Density	In-Place Asphalt Consistency Penetration	 Viscosity
Disintegration	High	High	High	Low
Distortion	Low	High	Low	High
Fracture	High	High	High(1)	Low(1)

(1) Laboratory studies coupled with structural analysis indicates that a reverse relationship could exist for pavements constructed with asphalt concrete thicknesses greater than 6 inches.

Table 2. Typical Temperature Susceptibility Values for Asphalt Cements Utilized in Texas

Refinery Code	Pen-Vis Number (PVN)*		
	AC-5	AC-10	AC-20
2	-0.4	-0.4	-0.6
4	-1.1	-1.1	-1.2
5	+0.9	+0.8	+0.7
6	-0.8	-1.1	-1.0
9	-0.9	-1.1	-1.4
10	-0.1	-0.3	-0.7
12	-0.1	-0.1	-0.1
15	-0.3	-0.7	-0.1
16	-0.8	-1.0	-1.0
26	-0.2	-0.1	-1.0
28	+0.2	0.0	0.0

*Calculated according to procedures contained in reference 18 and Appendix A of reference 1.

Table 3. Typical Properties of AC-3 Asphalt Cements Used in Texas - Spring 1981

Refinery Code	Original					After Test				
	Penetration 77°F Sec dmm	Viscosity 140°F Stokes	Viscosity 275°F Stokes	Flash Point 275°F Stokes	Specific Gravity	Viscosity 140°F Stokes	Viscosity Ratio	Penetration 77°F sec, dmm	Retained Penetrating Percent	Ductility 77°F cm.
4	221	309	1.40	575	1.018	824	2.67	99	45	141
5	338	277	2.80	600	0.974	418	1.51	224	66	141
6	281	337	1.70	600	1.014	588	1.75	182	65	131
11	312	304	2.00	600	0.984	476	1.57	194	62	131
15	276	332	1.58	575	1.018	673	2.03	158	57	141
26	270	319	1.94	560	1.018					

Table 4. Typical Properties of AC-5 Asphalt Cements Used in Texas - Spring 1981

Refinery Code	Original					After Test				
	Penetration 77°F sec dmm	Viscosity 140°F Stokes	Viscosity 275°F Stokes	Flash Point COC °F	Specific Gravity	Viscosity 140°F Stokes	Viscosity Ratio	Penetration 77°F sec, dmm	Retained Penetration Percent	Ductility 77°F cm
3	174	524	2.10	550	1.003	1257	2.40	91	52	141
4	156	462	1.72	490	1.025	1222	2.65	73	47	141
5	199	481	3.57	600	0.979	763	1.59	132	66	141
6	183	516	1.90	600	1.017	960	1.86	116	63	141
8	137	494		600	1.022					
9	145	509		600	1.014	909	1.78	92	63	141
12	209	512	2.47	550	1.022					
15	185	457	2.06	600	1.022	1061	2.32	99	54	
26	181	521	2.50	600	1.021					

Table 5. Typical Properties of AC-10 Asphalt Cements Used in Texas - Spring 1981

Refinery Code	Original					After Test				
	Penetration 77°F sec, dmm	Viscosity 140°F Stokes	Viscosity 275°F Stokes	Flash Point COC, °F	Specific Gravity	Viscosity 140°F Stokes	Viscosity Ratio	Penetration 77°F sec, dmm	Retained Penetration Percent	Ductility 77°F cm
2	86	1116	3.46	600	0.995					
4	91	895	2.32	600	1.029	2043	2.28	55	60	141
5	118	976	5.89	600	0.985	1524	1.36	84	71	141
6	99	1145	2.60	600	1.020	2018	1.76	63	64	141
8	91	986	2.40	600	1.021	1885	1.91	61	67	141
9	88	1102	2.60	600	1.023	2313	2.10	55	63	141
10	100	1005	3.24	600	1.003	2153	2.14	62	62	141
11	128	951	3.30	600	0.993	1678	1.76	90	70	141
12	123	1004	3.35	590	1.030	2106	2.10	80	65	141
15	107	1011	3.10	595	1.025	2542	2.51	63	59	141
16	105	886	2.37	600	1.028					
26	119	1007	3.40	600	1.023					

Table 6. Typical Properties of AC-20 Asphalt Cements Used in Texas - Spring 1981

Refinery Code	Original					After Test				
	Penetration 77°F sec, dmm	Viscosity 140°F Stokes	Viscosity 275°F Stokes	Flash Point COC °F	Specific Gravity	Viscosity 140°F Stokes	Viscosity Ratio	Penetration 77°F sec, dmm	Retained Penetration Percent	Ductility 77°F cm
2	63	1910	4.11	600	1.009					
3	75	1980	3.61	580	1.011	5108	2.58	50	67	141
4	60	1649	3.20	590	1.039	3771	2.29	38	63	141
5	80	1691	6.27	600	0.990	2842	1.68	58	73	141
6	67	1847	3.39	600	1.028	3683	1.99	44	66	141
9	60	1983	3.55	600	1.026	3320	1.67	42	70	141
10	57	2253	4.60	600	1.015	4878	2.17	40	70	141
12	83	1992	4.67	600	1.035	4302	2.16	52	63	141
15	80	2007	4.60	600	1.035	5253	2.62	49	61	141
16	63	1691	3.17	600	1.031	3829	2.26	38	60	141
17	58	2301	4.41	600	1.024	6104	2.65	35	60	141
24	95	2083	4.60	600	1.017	3757	1.80	69	73	141
26	87	1836	4.17	585	1.041					

Table 7. Texas State Department of Highways and Public Transportation-Standard Specifications for Asphalt Cement (1972)

Test	VISCOSITY GRADE				
	AC-3 Min. Max.	AC-5 Min. Max.	AC-10 Min. Max.	AC-20 Min. Max.	AC-40 Min. Max.
Viscosity 140 stokes	300±50	500±100	1000±200	2000±400	4000±800
Viscosity 275 F stokes	1.1 -	1.4 -	1.9 -	2.5 -	3.5 -
Penetration, 77 F 100g. 5 sec	210 -	135 -	85 -	55 -	35 -
Flash Point, C.O.C.E.	425 -	425 -	450 -	450 -	450 -
Solubility in trichloro-ethylene percent	99.0 -	99.0 -	99.0 -	99.0 -	99.0 -
Tests on residues from thin film oven test; Viscosity 140 F stokes	- 900	- 1500	- 3000	- 6000	- 12000
Ductility, 77F 5 cms per min cms.	100 -	100 -	70 -	50 -	30 -
Spot test	Negative for all grades				

Table 8. "Critical" Ductility-Penetration for Field Aged Asphalts ∞

Penetration 77°F	Ductility	
	Halstead (19)	Krchma (20)
25	≥ 10	≥ 5
30	≥ 20	≥ 8
35	≥ 33	≥ 18
40	≥ 52	≥ 30
50	≥ 100	≥ 65

Table 9. Guide for Selection of Asphalt Grade to Prevent Low Temperature Cracking.

Minimum Air Temperature, °F	<-10	-10 to +10	+10 to +30	>30
Asphalt Grade	AC-3 AC-5	AC-5 AC-10	AC-10	AC-20

Table 10. Recommendations for Selection of Asphalt Cement

Thickness of Asphalt Concrete, in.	Climate	Asphalt Cement Grade		Western States ASTM 3381
		AASHO M20 ASTM 3381	AASHO M226 ASTM 3381	
≤3	Cold[1] Moderate[2] Hot[3]	200-300 85-100 85-100	AC - 5 AC - 10 AC - 10	AR-1000 AR-4000 AR-4000
4-6	Cold Moderate Hot	120-150 60-70 60-70	AC - 5 AC - 20 AC - 20	AR-2000 AR-4000 AR-8000
>7	Cold Moderate Hot	120-150 60-70 40-50	AC - 5 AC - 20 AC - 40	AR-2000 AR-8000 AR-16,000

[1] Normal minimum daily temperature° of 10F or less; for extremely low temperature special studies are recommended.

[2] Normal maximum daily temperature° of 90F or less.

[3] Normal maximum daily temperature° greater than 90F.

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*As per U. S. Weather Bureau climatological reports.

(After Finn et al., ref. 32)

Table 11. Approximate Relationship of Air Temperature to Pavement Surface Temperature.

Air Temperature F	Pavement Temperature F
80	110
90	125
100	145
110	160

(after reference 33)

Table 12. Comparison of Asphalt Product Types Used For Surface Treatments and Seal Coats.

Asphalt Type	Advantages	Potential Problem Areas
Asphalt Cement	1. Few cure time problems: road surface will usually accept traffic without raveling when rolling is completed.	1. High spraying temperature required: a. May reduce durability of asphalt if overheated. b. Introduces operator safety and discomfort problems. c. Demands careful control to obtain uniform asphalt distribution. d. Is influenced by atmospheric and road surface temperatures. 2. Sensitivity to aggregate surface moisture. 3. Aggregate must be spread and rolled soon after asphalt is distributed.
Asphalt Emulsion (Anionic)	1. Can be applied with little or no heat on distributor. 2. Water dilution can be used except for rapid setting emulsions.	1. Separation of asphalt and water on long storage or after freezing. 2. Asphalt stripping with high silica aggregates 3. Emulsion may run off if road surface temperature is too high. 4. Cure time problems: traffic control required until cure is completed. 5. Will separate if mixed with cationic emulsions.
Asphalt Emulsion (Cationic)	1. Can be applied with little or no heat on distributor. 2. Good adhesion with all aggregate types. 3. Good adhesion with moist aggregates. 4. Can be used in cool weather. 5. Resistant to wash-off if rain occurs soon after placement.	1. Separation of asphalt and water on long storage or after freezing. 2. Emulsion may run off if road surface temperature is too high. 3. Water dilution may cause premature break 4. Cure time problems: traffic control required until cure is completed. 5. Will break if mixed with anionic emulsions.
Cut-Back Asphalt	1. Convenient to use: Uniform distribution 2. Requires lower spraying temperature than asphalt cement. 3. Can be used in cool weather 4. Residue will not be brittle in cold weather.	1. Cure time problems. 2. Cut-back solvent creates air quality problems 3. Waste of energy in cut-back solvent. 4. Solvents have low flash and fire points thus workman safety problems. 5. Bleeding problems.

Table 13. General Recommendations for Asphalt Selection Based on Climatic Conditions.

	Type of Asphalt	Construction Season	Spring			Summer			Fall			Winter		
		Climatic Region (Fig. 12)	I	II	III	I	II	III	I	II	III	I	II	III
Asphalt Cements**	AC-5			X	X							X	X	X
	AC-10		X	X	X			X		X	X	X	X	X
Anionic Emulsions	EA-HVRS		X*	X*	X	X*	X*		X*	X*		X*	X*	X
	EA-HVRS-90		X*	X*	X	X*	X*	X	X	X	X	X	X	X
Cationic Emulsions	EA-CRS-2				X									X
	EA-CRS-2h		X	X	X			X	X	X	X	X	X	X
Cutbacks	RC-2		X	X	X	X	X	X	X			X		
	RC-250		X	X	X	X	X	X	X			X		
	RC-3		X	X	X	X	X	X	X			X		
	RC-4		X			X	X	X	X					
	RC-5		X			X	X	X	X					
	MC-800		X	X	X	X	X	X	X			X		
	MC-3000		X	X	X	X	X	X	X			X		

Spring - March, April, May

Summer - June, July, August

Fall - September, October

Winter - November, December, January, February

*Do not use in high humidity areas
**Use caution when using dusty rock.
X-Indicates that this grade of asphalt should not be used for defined applications.

(After reference 33)

Table 14. Temperature Limitations for Asphalt Selection at the Time of Construction.

Temperature Limitations °F	AC	Anionic	Cationic
Min. Surf Temp. for 2 Days Prior	70	60	60
Min. Ambient Temp. for 7 Days After	70	60	60
(With moderate traffic after construction)	No rainfall in 48 hours		

(after reference 33)

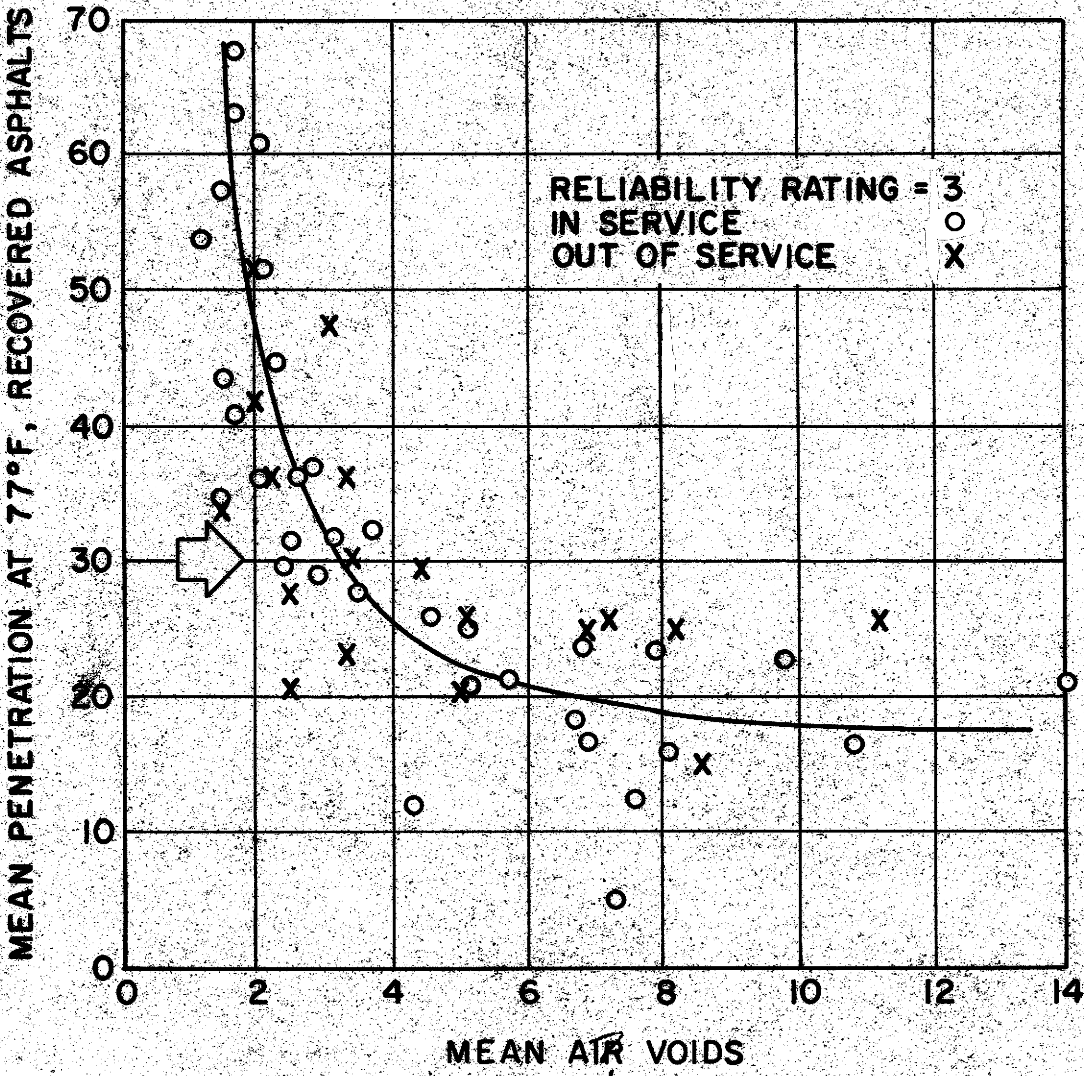
Table 15. General Recommendations for Asphalt Selection Based on Aggregate Type.

		Aggregate Type		
	Type of Asphalt	Natural Hydrophobic	Natural Hydrophilic	Lightweight
ASPHALT CEMENTS	AC-5			
	AC-10			
ANIONIC EMULSIONS	EA-HVRS		x	x
	EA-HVRS-90		x	x
CATIONIC EMULSIONS	EA-CRS-2			
	EA-CRS-2h			
CUTBACKS	RC-2			
	RC-250			
	RC-3			
	RC-4			
	RC-5			
	MC-800			
	MC-3000			

*Aggregate classification shown on Figure 2

X-Indicates that this grade of asphalt should not be used for defined application.

(After reference 33)



120-1

FIGURE 1. RELATION OF RETAINED PENETRATION AFTER FIELD AGING TO AIR VOIDS

(AFTER REFERENCE 12)

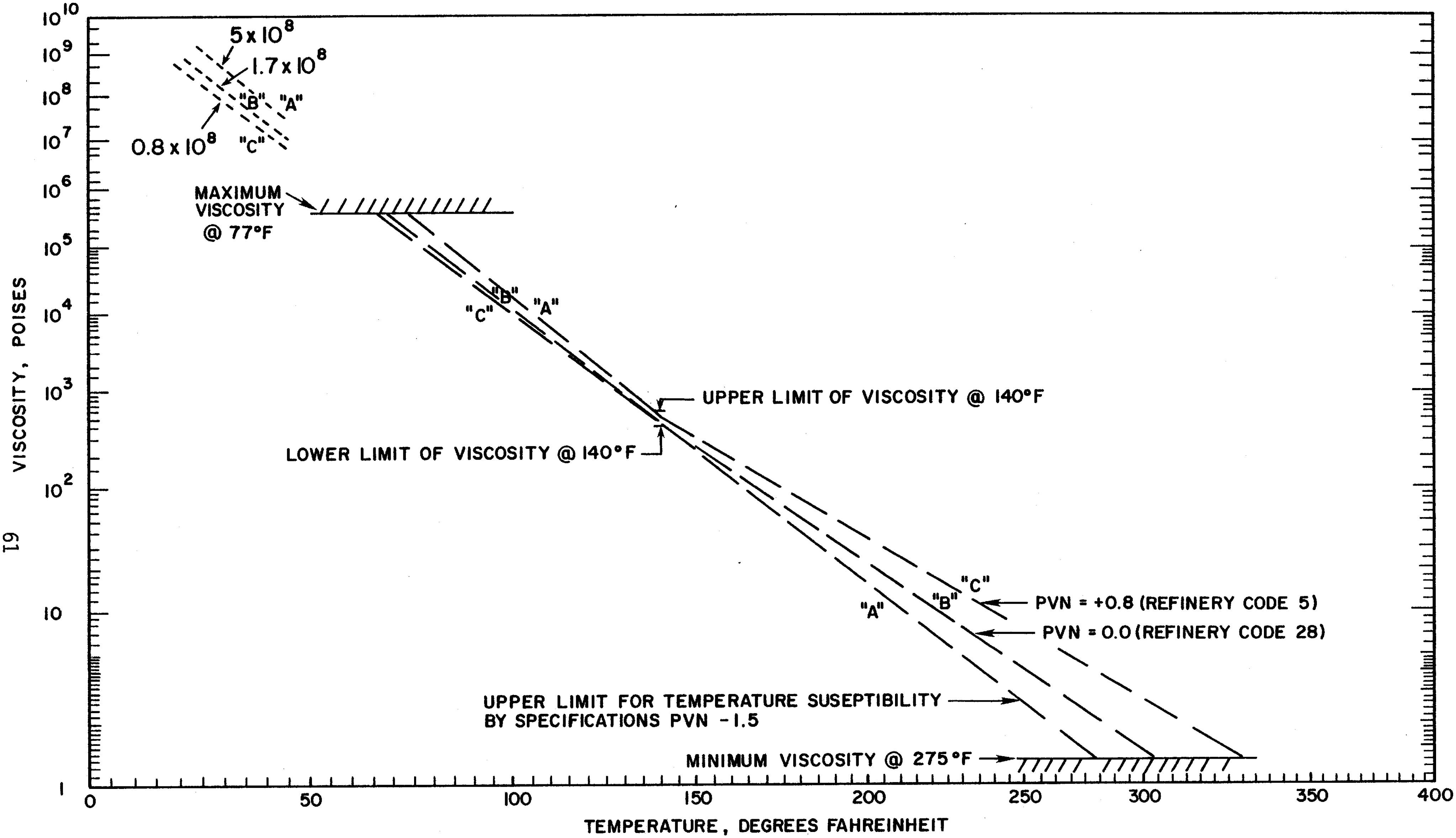


FIGURE 2. VISCOSITY - TEMPERATURE RELATIONSHIPS FOR AC-5 ASPHALTS

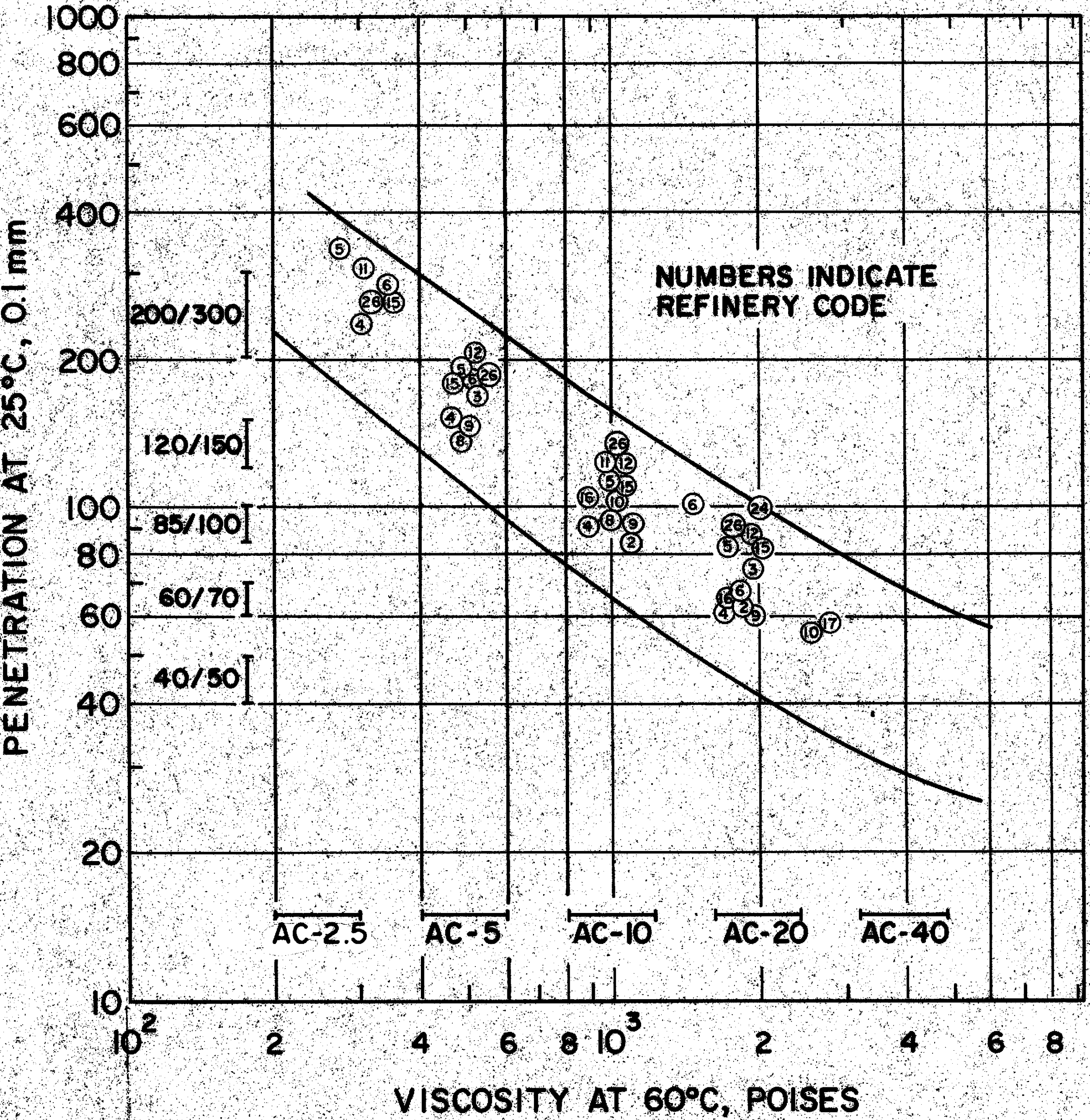


FIGURE 3. RELATIONSHIP BETWEEN VISCOSITY AT 60°C (140°F) AND PENETRATION AT 25°C (77°F) FOR ASPHALTS CEMENTS

(AFTER REFERENCE 14)

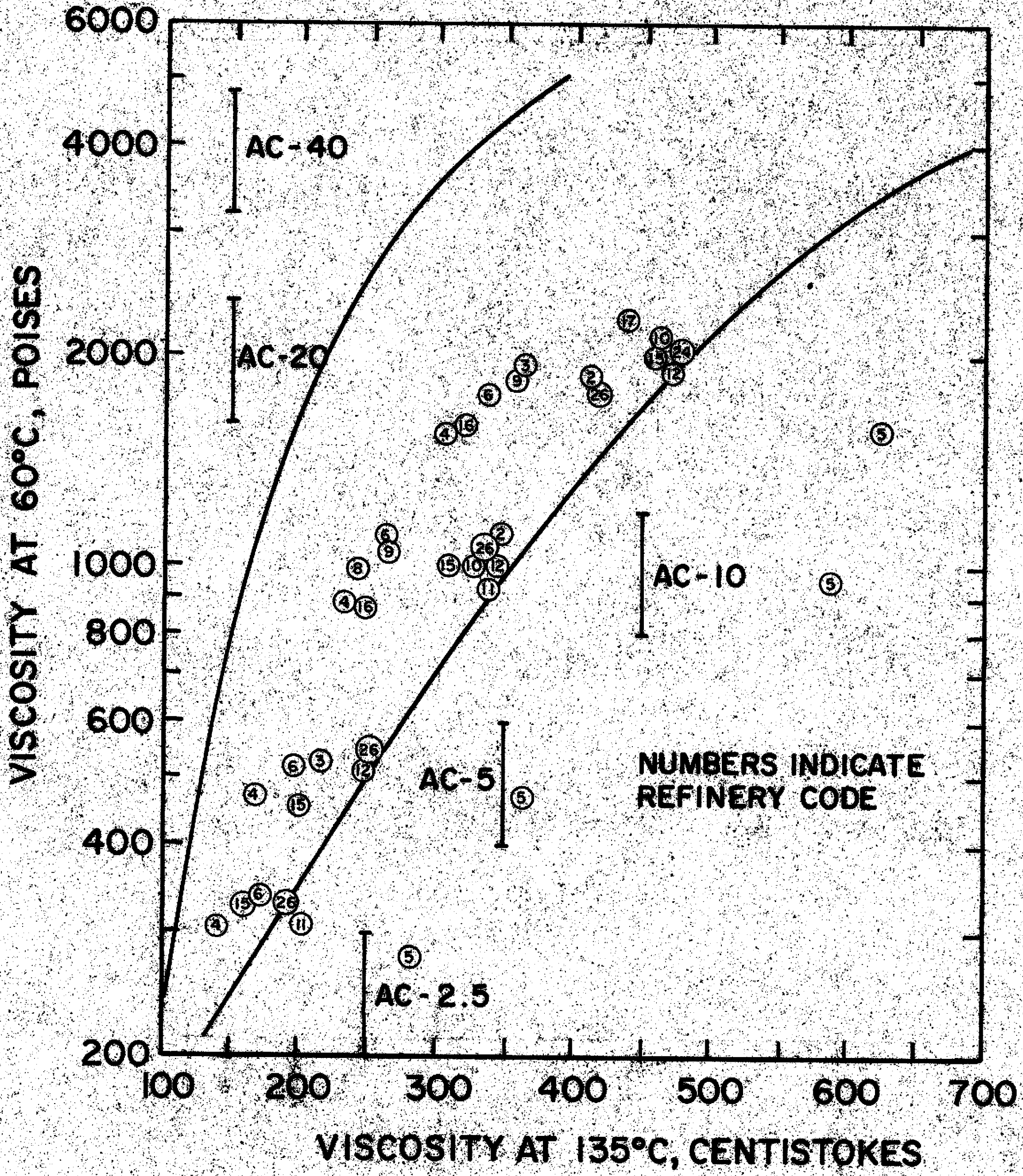


FIGURE 4. RELATIONSHIP BETWEEN VISCOSITY AT 60°C (140°F) AND 135°C (275°F) FOR ASPHALT CEMENTS

(AFTER REFERENCE 14)

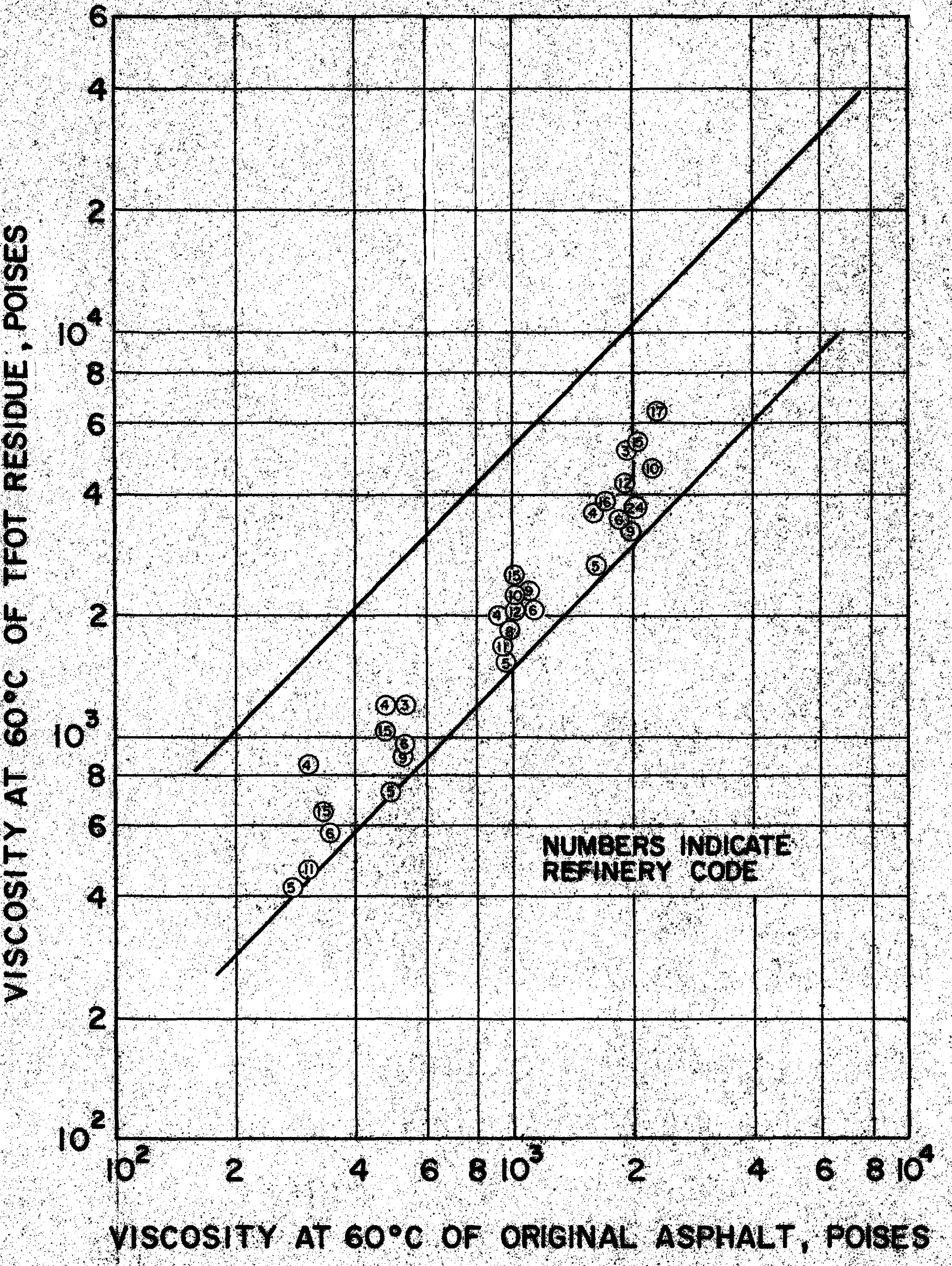


FIGURE 5. RELATIONSHIP BETWEEN VISCOSITY AT 60°C(140°F) FOR ORIGINAL AND HEATED ASPHALT CEMENTS

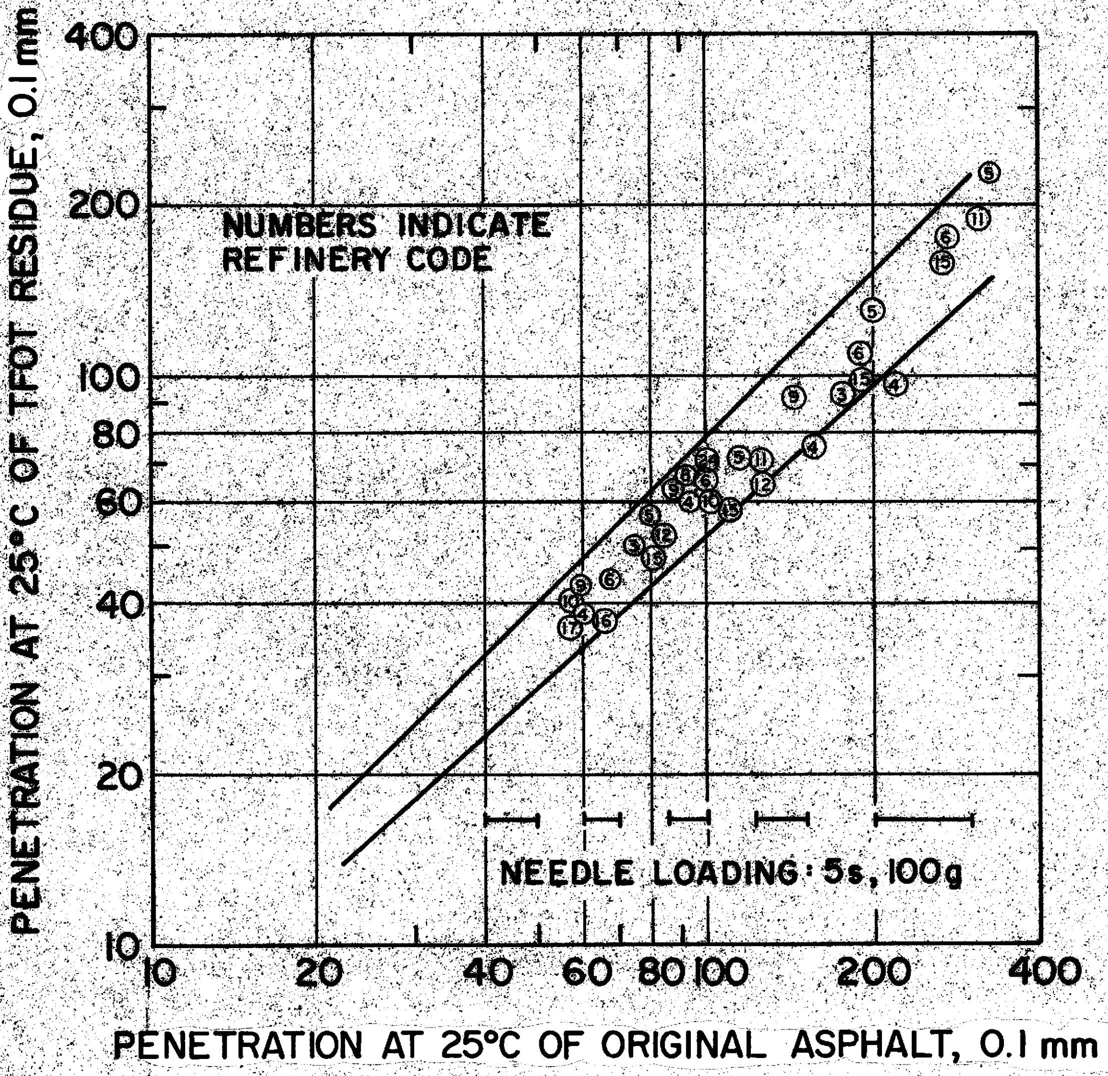


FIGURE 6. EFFECT OF TFOT HEATING ON PENETRATION AT 25°C (77°F) FOR ASPHALT CEMENTS

(AFTER REFERENCE 14)

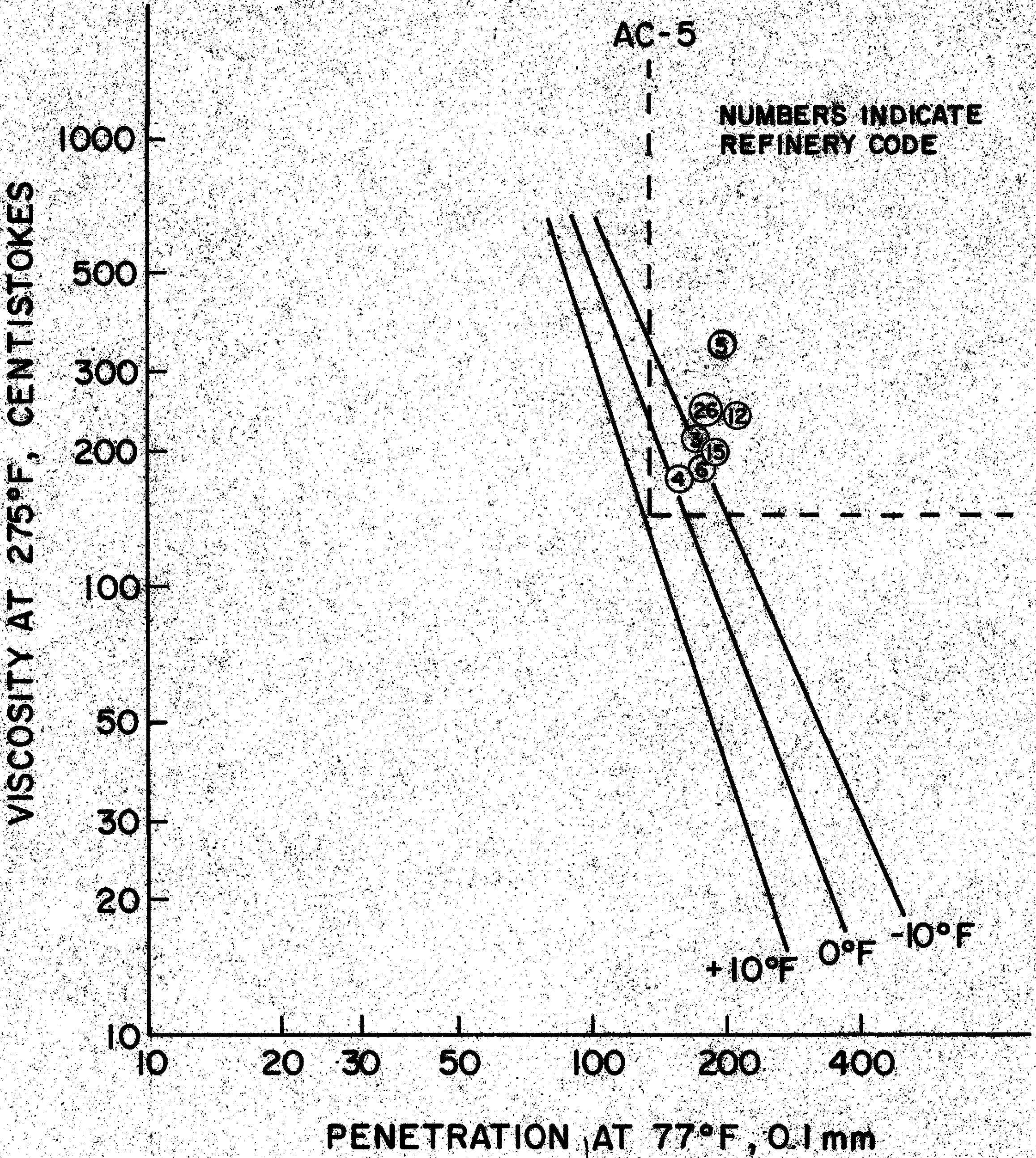


FIGURE 7. ALLOWABLE MINIMUM TEMPERATURE FOR AC-5 ASPHALTS

(AFTER REFERENCE 16)

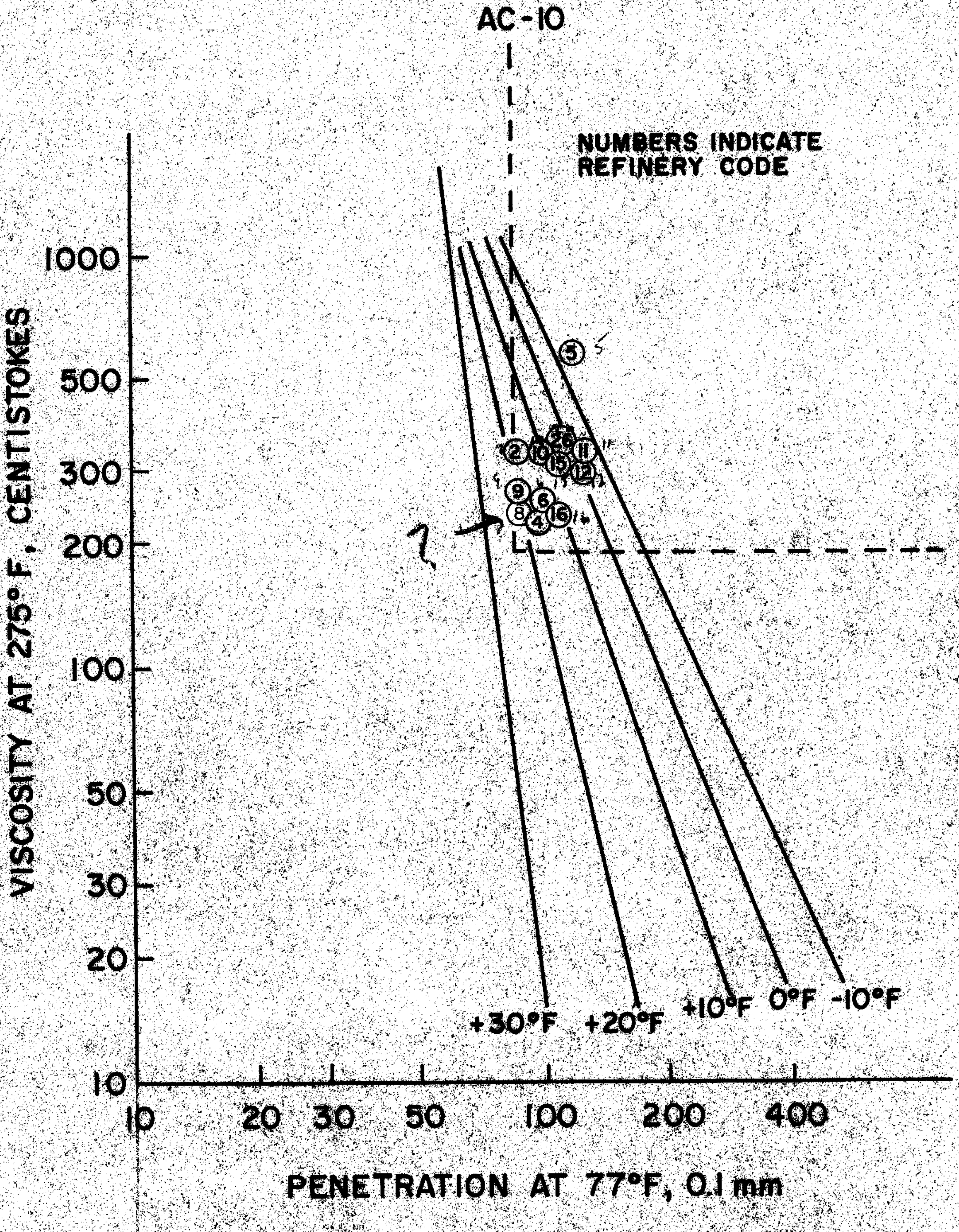


FIGURE 8. ALLOWABLE MINIMUM TEMPERATURE FOR AC-10 ASPHALTS

(AFTER REFERENCE 16)

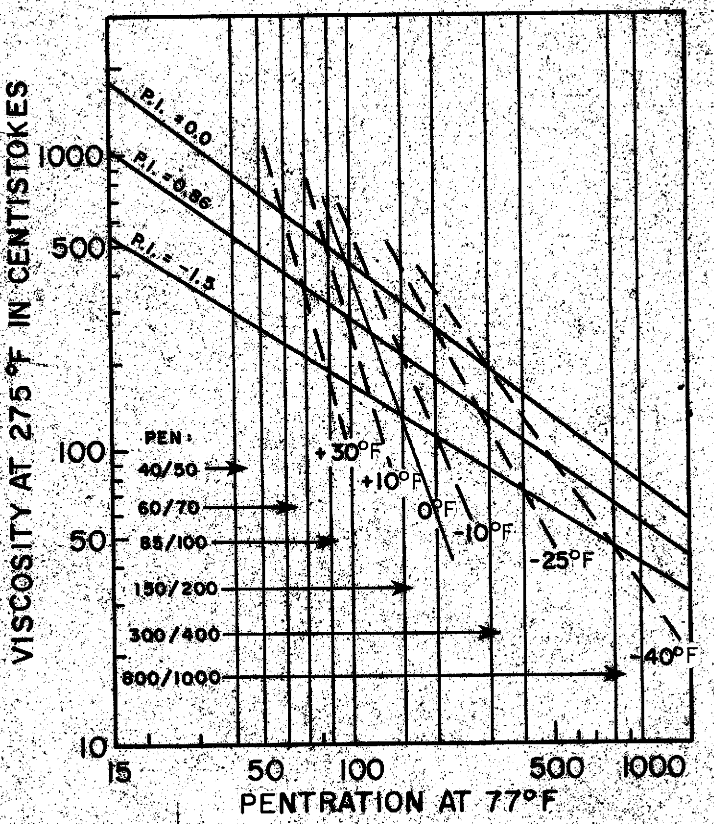


FIGURE 9. CHART FOR SELECTING GRADES OF ASPHALT CEMENT TO AVOID LOW-TEMPERATURE TRANSVERSE PAVEMENT CRACKING (AFTER REFERENCE 18)

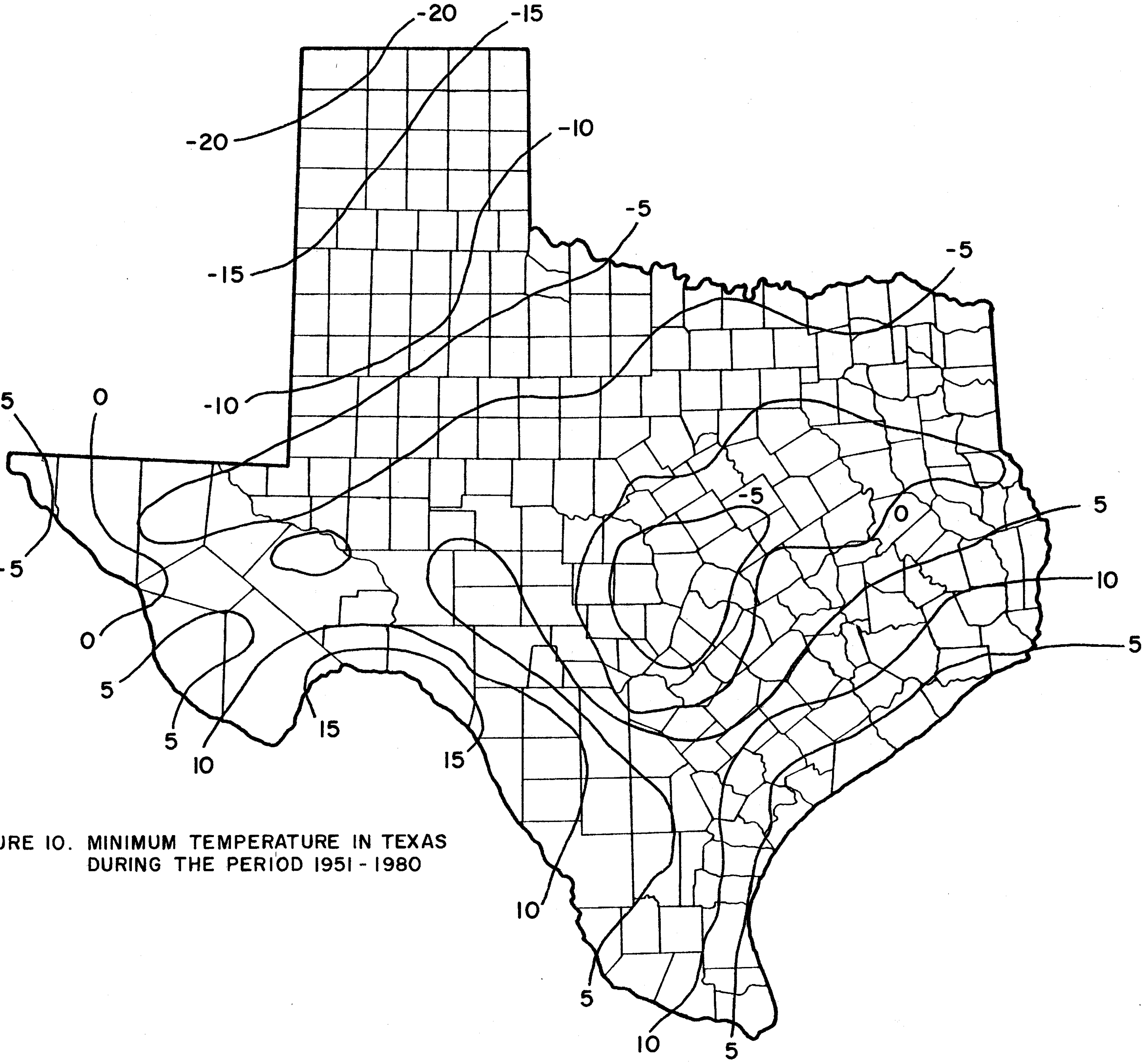


FIGURE 10. MINIMUM TEMPERATURE IN TEXAS
DURING THE PERIOD 1951 - 1980

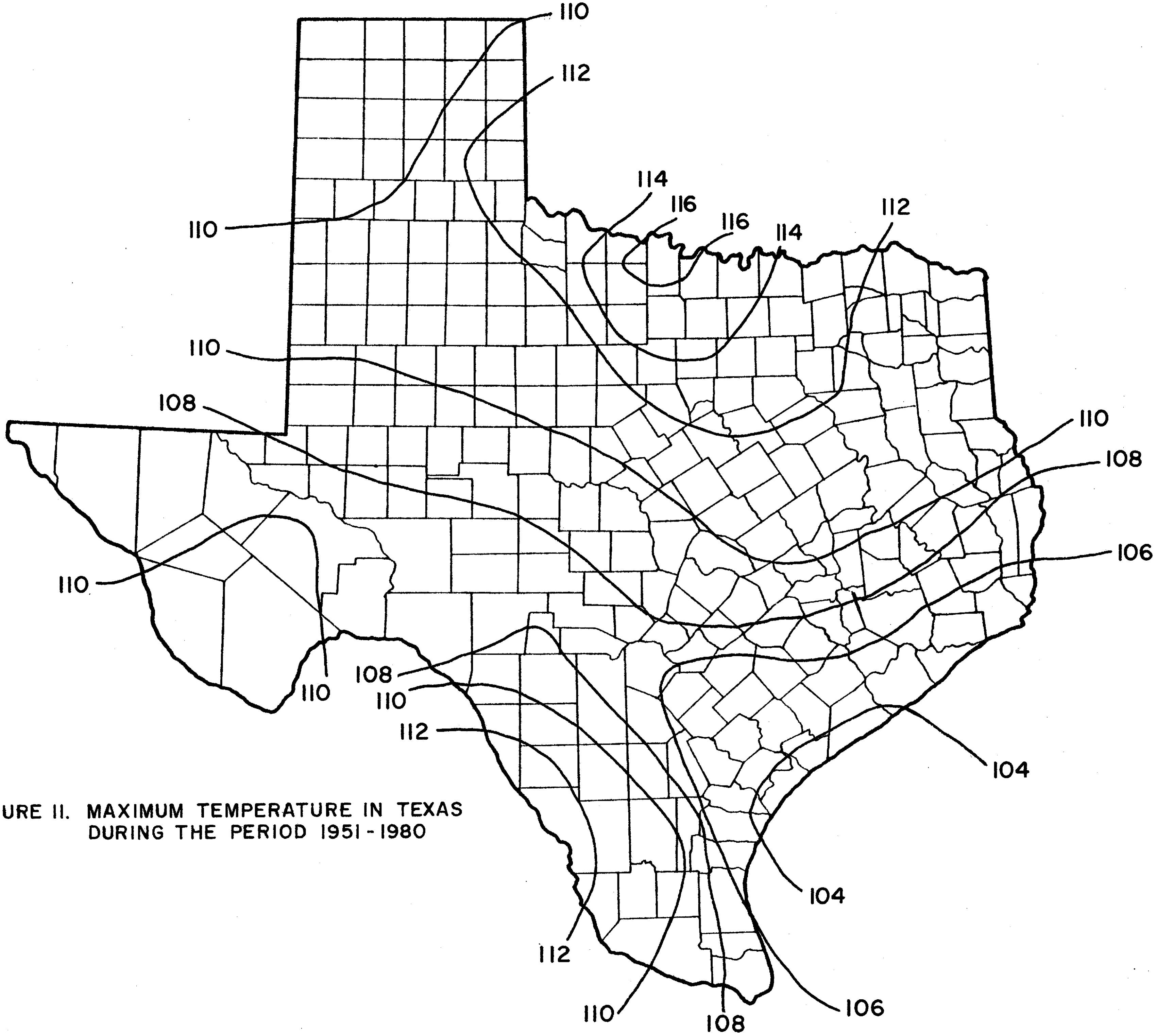
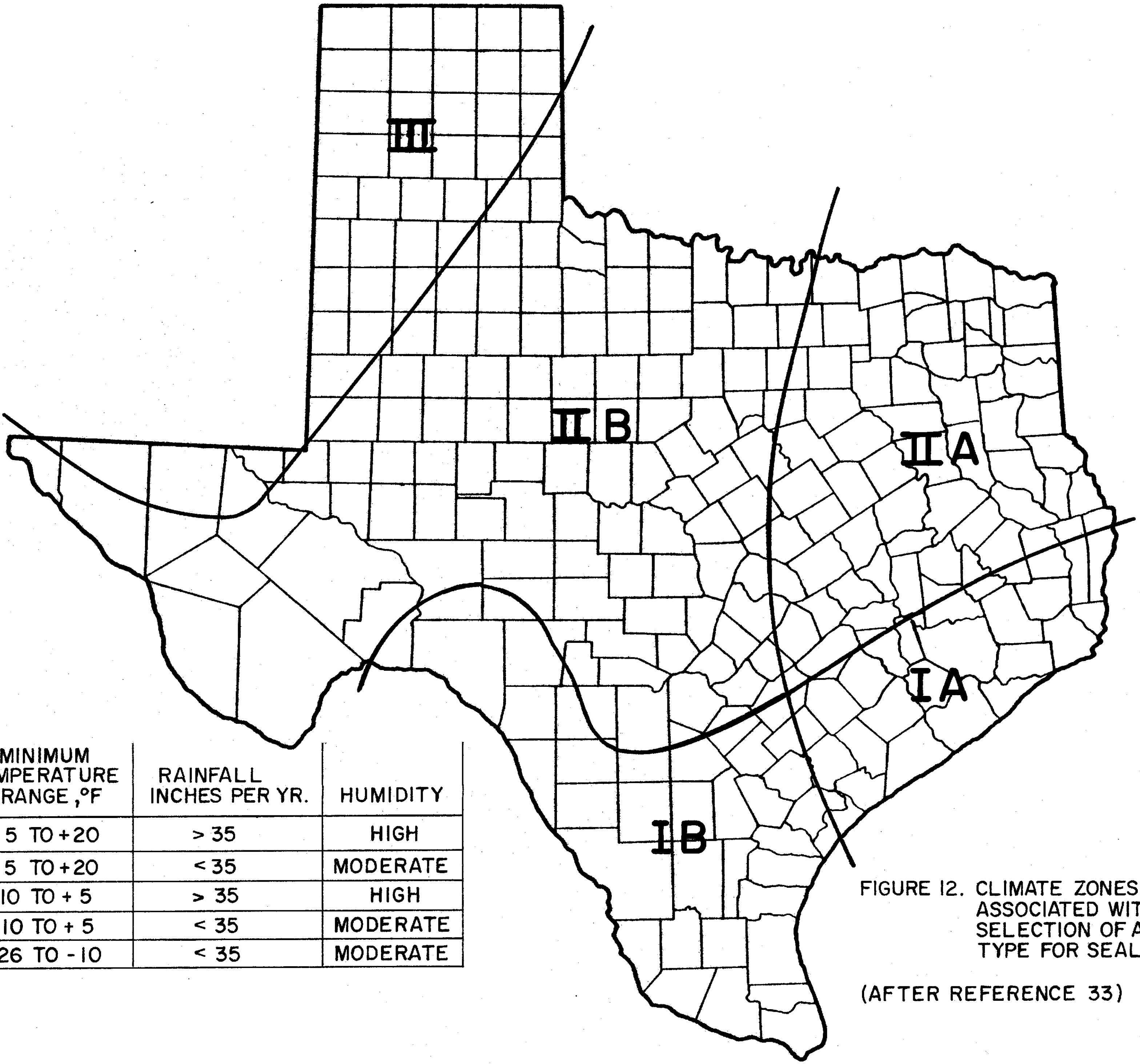


FIGURE II. MAXIMUM TEMPERATURE IN TEXAS DURING THE PERIOD 1951-1980



ZONE	MINIMUM TEMPERATURE RANGE, °F	RAINFALL INCHES PER YR.	HUMIDITY
IA	+5 TO +20	> 35	HIGH
IB	+5 TO +20	< 35	MODERATE
IIA	-10 TO +5	> 35	HIGH
IIB	-10 TO +5	< 35	MODERATE
III	-26 TO -10	< 35	MODERATE

FIGURE 12. CLIMATE ZONES ASSOCIATED WITH SELECTION OF ASPHALT TYPE FOR SEAL COATS

(AFTER REFERENCE 33)

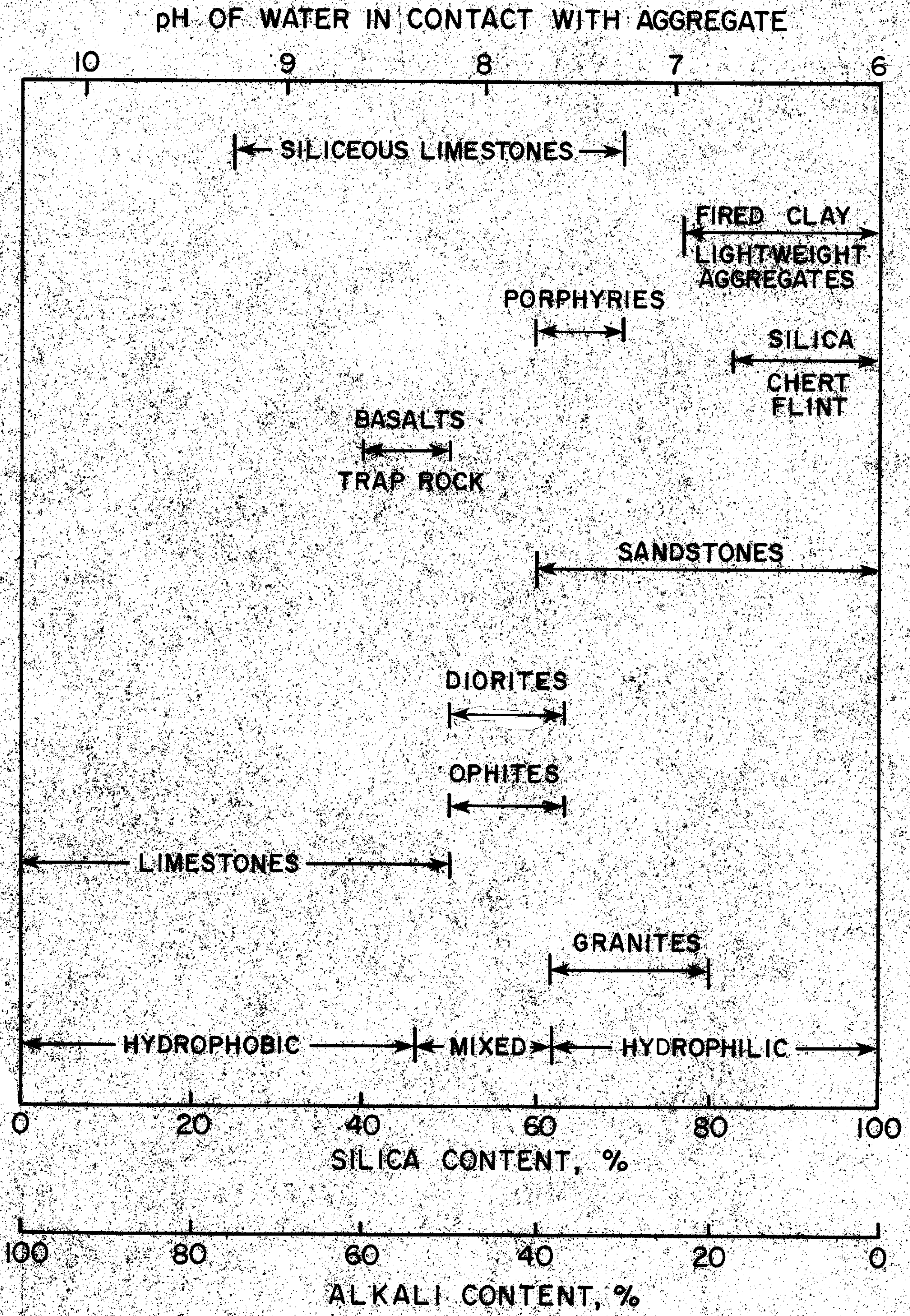


FIGURE 13. AGGREGATE TYPE CLASSIFICATION CHART (AFTER REFERENCE 34)