Design and Construction of Epoxy Asphalt Concrete Pavements

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A new paving material developed specifically to withstand high temperature jet blast and fuel spillage and to provide the high load-carrying ability demanded by modern airfield and highway traffic is described. Epoxy asphalt concrete (EAC) is a combination of graded mineral aggregate and an asphaltic binder containing an epoxy resin which is converted into a polymer with unusual solvent and heat resistance.

The mechanical properties of EAC as well as its resistance to heat and solvents are summarized. Various aspects of mix and thickness design in relation to the production of EAC pavements are discussed and preferred mix plant and construction practices which have been developed from field experience are outlined.

The minor additions required for handling the binder in conventional hot-mix paving plants are mentioned and the control of polymerization rate by choice of aggregate temperature is described. Importance of aggregate gradation and binder content in achieving dense, impermeable pavements is demonstrated, and a preferred range of dense gradings compatible with good mix workability and aggregate availability is shown.

Spreading of the mix should be accomplished before the binder viscosity exceeds about 60 poises, and the influence of this fact on working time and choice of mix temperature is discussed. From compaction studies of epoxy asphalt concrete, preferred practices have been developed, and the results of these studies were found to be in good agreement with the theory of compaction of asphaltic concrete mixes.

Thickness design of EAC pavements using some of the existing methods of flexible pavement design has been considered. Some examples are shown and adjustments in the design procedures are suggested.

● FOREMOST among the problems facing the paving industry are those created by the steadily increasing loads imposed on airfields and highways. On airfields the structural problems are further complicated by the occurrence of damage to pavements by fuel and solvent spillage and by high temperature jet blast associated with modern military and commercial jet aircraft.

As a result of years of laboratory experimentation and field development work, a new paving material, epoxy asphalt concrete (EAC), has come to the fore as a product of great interest. Because of its combination of unusual mechanical properties and chemical resistance, EAC offers a simultaneous solution to the problems associated with heavy loads, high temperature blast and fuel spillage.

In a previous paper (1) the mechanical properties, heat resistance, and solvent resistance of epoxy asphalt concrete were discussed in detail and demonstrated by laboratory tests and by examples of field performance under conditions of actual use. The purpose of the present paper is to discuss some of the most important aspects of construction with EAC and to indicate in a preliminary way how the mechanical properties of the material may be used in thickness design of epoxy asphalt concrete pavements.

PRODUCTION OF EPOXY ASPHALT CONCRETE (EAC)

This new material of construction is produced in conventional hot-mix plants normally employed for preparation of asphaltic concrete mixes. Graded mineral aggregates are dried, screened and proportioned in the normal fashion and mixed in the pugmill with EPON (Trademark Shell Oil Company) asphalt binder, which initially has appearance and properties similar to asphalt. A chemical reaction which takes place in the binder during mixing, hauling, spreading, and compaction, and for some time thereafter, converts the binder into a thermoset plastic which is flexible, extensible and has high tensile strength. The mix is spread by conventional, self-propelled paving machines or by hand-raking and is compacted with steel and rubber-tired rollers of the normal type. Construction techniques and specifications for the successful application of this new product have been established in cooperation with the Products Application and Research Departments of Shell Oil Company in a series of field installations conducted during the past four years using commercial hot-mix plants and paving equipment. The finished pavement has the appearance of asphaltic concrete but its resistance to attack by solvents and fuels, its strength retention under high temperature jet blast, and its high load-carrying capacity represent great improvements over the properties of normal asphaltic concrete.

HANDLING THE BINDER IN THE MIX PLANT

The binder used in the production of EAC consists of a blend of a liquid epoxy resin and a paving grade asphalt containing an additive which functions as a flexibilizing coreactant. The asphalt containing the additive is stored and transferred in the existing facilities of the hot-mix plant and a minor addition to the plant is required to provide for pumping of the epoxy resin to the weigh platform where blending of the binder components is accomplished in the weigh bucket with brief stirring.

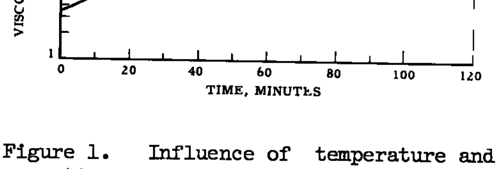


Figure 1. Influence of temperature and time on viscosity of the binder.

Influence of Temperature

The chemical reaction in the binder system which begins with the addition of the epoxy resin causes the visosity of the binder to increase steadily with the passing of time. Two examples are shown in Figure 1. The rates of reaction and of viscosity increase are readily controlled by the choice of temperature, an increase in temperature resulting in a higher rate of viscosity rise. A detailed knowledge of the influence of temperature on reaction velocity and viscosity has been obtained in studies of the reaction kinetics. As in normal plant practice, the binder is transferred promptly from the weigh bucket to the pugmill for mixing with the aggregate, and the temperature of the binder is determined thereafter by the temperature of the aggregate which constitutes over 90 weight percent of the mix. For good mixing with aggregate in the pugmill in a period of less than 1 min, a binder viscosity of less than about 20 poises is advisable, as indicated in Figure 1. Although the binder and aggregate can be successfully mixed at temperatures as low as 215 F, the aggregate may not be sufficiently dry at this low level and a somewhat higher minimum aggregate temperature is normally used for this reason. The maximum aggregate temperature which may be used is determined by the amount of time required for hauling, spreading, and compacting the mix. At high temperatures the polymerization reaction proceeds more rapidly, and the viscosity of the binder increases more rapidly than at low temperatures (Fig. 1). Laboratory and field experience have shown that the mixing, hauling and spreading of the mix should be accomplished by the time the binder viscosity has reached 60 poises in order to be able to obtain the desired degree of compaction readily with conventional rollers. The aggregate temperature to be used in a particular construction job will be determined largely by the hauling time involved because the mixing time in the plant and the time required for spreading the mix are essentially constants. Where the hauling time is short, relatively high temperatures can be used, but for long hauls lower temperatures are chosen. The practical range of temperatures for handling the mix falls within the normal operating range of hot-mix paving plants.

CHARACTERISTICS OF THE CURED BINDER

If desired, the binder may be cured in the form of sheets or other shapes for laboratory testing. Test methods devised for the characterization of elastomers and plastics are particularly applicable. Tensile tests of dumbbell-shaped specimens according to ASTM method D-412-51T at a rate of 20 in. per min at room temperature show that the binder has a tensile strength of 1,000 psi and an elongation at break of 200 to 300 percent. Correction of the tensile test results for the change in cross-section area during the test, gives a true tensile strength of 3,000 psi.

The suitability of this material for use as a binder at high temperatures is shown by the fact that it has no melting point and holds its shape at temperatures as high as 800 F. Heating to a high temperature does not destroy the good low temperature flexibility of the binder as indicated by the results of the Fraass test. In this test (Institute of Petroleum method 80/53) a 0.5-mm thick layer of asphalt or other product is placed on a spring-steel strip and subjected to periodic bending which produces a maximum tensile strain of 3 percent in a period of 11 sec. The temperature is gradually lowered until the specimen fractures under this strain. A 60 penetration paving asphalt fractured at +16 F in this test whereas epoxy asphalt binder failed to fracture at -31 F. After exposure to a temperature of 760 F for 5 min the Fraass breaking point of the asphalt was raised to +25 F whereas the epoxy asphalt still failed to fracture at -31 F. This binder resists attack by fuels and solvents which rapidly dissolve normal paving grade asphalts.

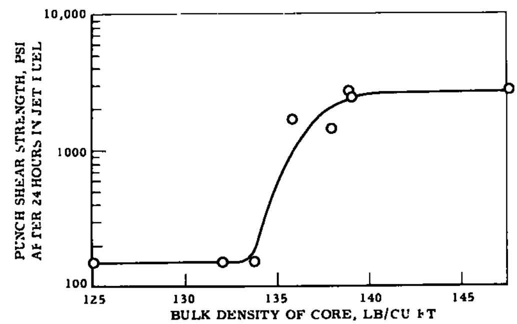


Figure 2. Influence of density on solvent resistance and shear strength of epoxy asphalt concrete.

MIX DESIGN

In many of the applications of EAC the material has been used as an overlay pavement to protect underlying asphaltic concrete from damage by solvents and fuel spillage. Where this is the major function of the overlay, it is desirable to produce a dense pavement, impermeable to these liquids. Laboratory and field investigations have also shown that the retention of shear strength of the EAC itself in contact with jet fuels is best when the pavement density is high. This is shown in Figure 2 for a group of cores taken from a series of field installations all employing the same aggregate. A punch shear test was used to measure the strength of ½-in. thick specimens of the overlays after 24 hr immersion in jet fuel. The test consists of placing the specimen over a ½-in. diameter hole in a steel plate and driving a 7/16-in. diameter cylindrical rod against the specimen with a testing machine at a rate of 0.2 in. per min until failure by shear results. In Figure 2 a transition from low to high shear strength is shown to occur as the density of the pavement increases over a fairly narrow range. The air void content decreases from about 6 percent to 3 percent (basis saturated surface dry aggregate density) as the shear strength after soaking in jet fuel increases from about 160 to 2,500 psi (Fig. 2). On the basis of data of this type, supplemented by permeability measurements on field installations, an air void content of 4 percent (based on saturated surface dry specific gravity of the aggregate) has been set as a goal in the construction of overlays where solvent resistance is important.

This low air void content is achieved by the use of a dense graded aggregate, high binder content in the mix, and by the use of heavy rollers in the compaction operation.

The Aggregate

For overlay pavements ¾ to 1 in. thick, a maximum aggregate size of ¼ in. is used, and in general a maximum size less than one-half the thickness of the pavement is recommended. Aggregates complying with conventional quality and gradation specifications are used. In order to provide impermeable pavements with high strength, dense graded aggregates are preferred. Andreasen and Anderson have shown (2) that aggregate grading curves (with the exception of skip graded systems) can generally be represented fairly well by equations of the form

$$P = CK^q \text{ or } \log P = q \log K + C^1$$

in which P = % of the aggregate passing a sieve of size K;
q = slope of the plot of log % passing each sieve versus log of sieve size; and
C = a constant, $C^1 = \log C$.

Using this type of representation of aggregate grading, Nijboer (3) has developed a simple graphical method of determining the voids in mineral aggregate from the grading curve. He also showed that the aggregate gradation which leads to minimum voids in the mineral aggregate or maximum density is a gradation in which the slope (q) of the plot of log percent passing various sieves versus log of sieve size is 0.45. Varying the slope, q, of the grading curve over the range 0.3 to 0.6 causes a variation of voids in the mineral aggregate of about 2 percent, indicating that the gradation may be varied within the fairly wide limits shown in Figure 3 without departing greatly from the maximum density. The various maximum density gradings proposed by Fuller, Campen (4), and Hveem (5) all fall within the range of gradings defined by the q values of 0.3 to 0.6. However, aggregate with ¼-in. maximum size and a q value of 0.3 contains more than 20 percent material passing the 200 mesh screen and paving mixes made with such gradings have been found to be extremely difficult to lay smoothly. Aggregate gradations falling anywhere within the boundaries defined by q values of 0.45 to 0.6 (Fig. 3) have been found by field experience with EAC to be the most practical of the dense graded mixes from the point of view of availability and workability.

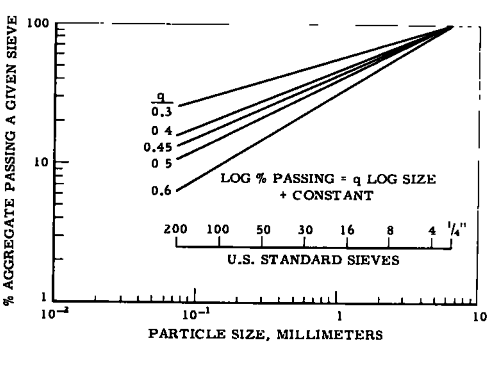


Figure 3. Aggregate gradations for dense, impermeable pavements.

Binder Content

The binder content to be used in the mix may be estimated from the voids in the mineral aggregate (VMA) after deciding on the acceptable level of voids in the compacted mix (VCM), as follows:

% VMA - % VCM = V% Binder Required.

For example, if the voids in the mineral aggregate amount to 21.5 percent and it is desired to have 4 percent voids in the compacted mix then 17.5 percent volume binder will be required in the mix. If the apparent specific gravity of the aggregate is 2.5, in this example, the binder will constitute 8.2 percent weight of the total mix or 8.9 percent of the weight of the mineral aggregate.

The Marshall method of mix design has been used successfully for EAC with stability of the cured mix reaching values as high as 20,000 lb at 140 F. In general, the binder content used in practice is higher than the binder content giving maximum Marshall stability. Field studies and commercial installations with a variety of mixes have shown 7 to 10 percent weight of binder basis aggregate to be the preferred range for ease of workability in the preparation of dense, impermeable EAC desired for good solvent resistance. These high binder contents can be used without producing the unacceptably low stability usually experienced with asphalt because of the high strength and heat resistance of the epoxy asphalt binder.

PLACEMENT AND COMPACTION OF THE MIX

Surface Preparation

When the epoxy asphalt concrete is used as an overlay on existing pavements, the surface should be swept free of dust and dirt and a suitable tack coat should be applied. Tack coats of emulsified asphalt, cutback asphalt and penetration grade asphalt have been used successfully in many installations. Where the pavement is subjected to normal pretakeoff conditions by military or commercial jet aircraft, an asphalt tack coat appears adequate. Where the pavement is subjected to prolonged high temperature blast, such as in maintenance and engine overhaul areas, a tack coat of the epoxy asphalt binder may be required.

Synchronizing Plant and Field Operations

As mentioned earlier, the temperature used at the mix plant is chosen so that sufficient time is allowed for mixing, hauling, and spreading of the mix before the binder viscosity reaches about 60 poises. The mix is produced at such a rate that it can be spread by the paving machine at a convenient speed. This simple scheduling of mix plant and laying operations avoids undesirable holding time for the mix in trucks at the job site or periodic starving of the paving machine. The mix has been spread successfully by hand-raking and by several types of self-propelled finishing machines commonly used in hot-mix paving.

Compacting the Mix

Rolling studies have been conducted on EAC mixes at field installations with steel rollers ranging from 3.5 to 12 tons, and with rubber-tired rollers. The degree of compaction obtained under a variety of conditions was assessed by determining density and air void content of cores taken from the pavements after compaction. The results obtained in these studies with EAC are in general agreement with experience in compaction of asphaltic concrete. By use of a variety of rollers the degree of compaction was found to be directly proportional to roller weight (P), and to the number of passes (N), and inversely proportional to wheel width (W). Degree of compaction was shown to be inversely proportional to the viscosity of the mass (η_m) by varying the binder content of the mix at constant temperature and constant age of the mix. These results agree with those obtained by Nijboer (3) who showed that the degree of compaction or "rolling factor" (R_f) for asphaltic concrete is related to the roller geometry and speed, consistency and thickness of the mix and the number of passes by the following expression

$$R_f = \frac{PN}{WD\eta_m} (h/v)^{0.4}$$

in which

D = roller diameter;

h = pavement thickness; and
v = roller velocity.

For binder contents of 8.5, 9.5, and 10.5 percent in dense graded sand sheet mixes, Nijboer found that an air void content of 4 percent is obtained during compaction when the magnitude of the rolling factor reaches values of 43×10^{-4}, 28×10^{-4}, and 14×10^{-4} inch-pound-seconds, respectively. From the authors' rolling studies with EAC it was concluded that the desired density and low void content can be obtained by making the break-down roll with 10- or 12-ton steel rollers followed by surface finishing with rubber-tired rollers with weights of 2,000 lb per wheel and tire pressures of about 70 psi or higher.

PROPERTIES AND PERFORMANCE OF EPOXY ASPHALT CONCRETE

A program has been undertaken in which the mechanical properties of this new paving material have been investigated in the laboratory, and performance under conditions of actual use has been determined in the field. The results of these investigations, described in detail in a previous paper (1), will be briefly summarized here. The field installations, consisting of ½- to 1-in. thick overlay pavements, have been placed in cooperation with the Products Application and Manufacturing-Research Departments of Shell Oil Company. These studies have been made with mixes employing dense graded aggregates with a maximum particle size of ¼ in.

Stability

By means of the Marshall test the stability of epoxy asphalt concrete has been determined at several levels of binder content. The specimens were prepared with 75 blows on each face and were cured 4 hr at 250 F. The stability of EAC at 140 F is in the range of 10,000 to 20,000 lb as compared with a range of 800 to 3,500 lb for conventional asphaltic concrete made from this dense graded crushed aggregate. There is little apparent damage to the EAC specimens during Marshall testing, and when the load is removed the specimen rebounds, about 60 to 70 percent of the "flow value" actually being an elastic and recoverable deformation (Table 1). Asphaltic concrete does not show this type of recovery but remains permanently deformed after the Marshall test.

TABLE 1

MARSHALL STABILITY AND FLOW VALUES FOR EPOXY ASPHALT CONCRETE AND ASPHALTIC CONCRETE AT 140 F

% Binder Basis Aggregate	Average Marshall Test Values for Duplicates				Bearing Capacity,[1] psi
	Stability (lb)	Flow in Inches			
		Total	Rebound	Permanent	
6	15,900	0.17	0.12	0.05	973
7	19,900	0.18	0.12	0.06	1,135
8	16,100	0.22	0.13	0.09	706
6% Asphalt 85/100	3,560	0.14	0	0.14	275

[1]Tire pressure which can be tolerated at 140 F without producing a compressive strain in excess of 1 percent.

In Table 1 the bearing capacities of epoxy asphalt concrete calculated by the method of Metcalf (6) are shown to be in the range of 700 to 1,100 psi as compared with 275 psi for the asphaltic concrete made with the same aggregate. This represents an improvement which is of particular significance in view of the high tire pressures and wheel loadings which are encountered in modern military aircraft.

The ability of pavements to retain high load carrying capacity after many repeated loadings is particularly important in taxiways and runways where aircraft traffic is channelized. Repeated loading of epoxy asphalt concrete simulating thousands of coverages by heavy bomber traffic has shown that epoxy asphalt concrete retains high stability and low flow values and resists densification.

Bearing Capacity of Field Installations

The chemical reaction which converts the binder from a viscous liquid to a nonmelting plastic is still in progress when the hot mix is spread and compacted and continues from some time in the pavement. The progress of the reaction in the pavement may be followed by determining the bearing capacity of the pavement periodically by means of the 90-deg cone penetrometer test which gives bearing capacity results in good agreement with theory when used on sand sheet mixes of the type involved in epoxy asphalt overlays. Figure 4 shows data taken on an EAC overlay placed at an aircraft maintenance base in the San Francisco area. This overlay supported a truck with a 17,700-lb rear axle load without shoving within 15 min after compaction. One day after placement the pavement could withstand a tire pressure of 200 psi and this increased to 740 psi within one week. A bearing capacity in the range 2,000-3,000 was attained in 30 days.

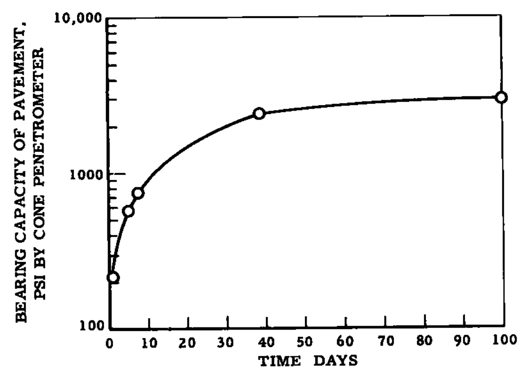


Figure 4. Increase of bearing capacity with time.

These bearing capacity values are far beyond the requirements of aircraft now in use, the highest tire pressures currently encountered being about 500 psi on some aircraft of the U.S. Navy, as described by Hansche (7). A practical example of the need for the high bearing capacity of EAC is found in areas where vehicles such as fork-lift trucks and steel-wheeled dollies carrying heavy loads on small diameter wheels are used. Such a case was encountered in an aircraft assembly plant where large sections of structural members were being transported on trains of steel-wheeled dollies with wheel loads of 800 lb per inch of wheel width. The rough, cracked surface of the portland cement concrete floor was causing damage to the aircraft sections and this condition was alleviated by placement of a ½-in. EAC overlay to serve as a new smooth running surface. The overlay was placed during a weekend and had developed sufficient bearing capacity by the following Monday to support the heavy loads without indention of the pavement.

Fuel and Solvent Resistance

The relative solvent resistance of low air void content asphaltic concrete and epoxy asphalt concrete to jet fuel at 140 F is given in Table 2. Asphaltic concrete disintegrates within 6 hr under these severe conditions while EAC retains a Marshall stability of about 15,000 lb.

The solvent resistance of epoxy asphalt concrete pavements has been tested in a bulk depot where a small amount of spillage and dripping of fuels and lubricants occurs constantly, requiring frequent replacement of asphaltic concrete. A ½-in. overlay of EAC has been effective in protecting the underlying pavement from softening by fuels and lubricants for several years.

An extremely severe condition of solvent and fuel damage was encountered at the maintenance base of a commercial airline in the San Francisco area. As part of the maintenance and overhaul routine, planes are placed on a designated area where engines soiled by oil leaks are washed down with a petroleum solvent (resembling paint thinner) which falls on the pavement. Oil filter changes are made with some spillage; fuel tank drains at 18 locations on the aircraft are opened to remove water and some highly aromatic aviation gasoline as well. Hydraulic fluids frequently accumulate in small amounts on the pavement. As a result of the good performance of an EAC overlay in this severe service the airline elected to protect a three-acre area of asphaltic pavement at a new jet maintenance base with an epoxy asphalt overlay.

Jet Blast Resistance

Epoxy asphalt overlays 1-in. thick have been placed on spalled portland cement concrete slabs and on eroded flexible pavements in overhaul and maintenance areas used for jet planes at several military air bases where thermocouples have been installed in the overlays for temperature measurements during blast tests. Some of these tests used cycles which simulated normal pretakeoff operation and consisted of periods of idle power operation and of 100% power or "military" operation. In other tests, prolonged use of the afterburner was also included which resulted in surface pavement temperatures as high as 800 F. The over-all performance of the overlay in these tests, which involved conditions far exceeding the severity and duration expected in normal use by military aircraft, was judged to be excellent. It has been pointed out by the Federal Aviation Agency that the severity of jet blast and temperatures encountered with commerical airline jet planes is considerably less than in the case of militay aircraft.

TABLE 2

SOLVENT RESISTANCE OF EPOXY ASPHALT CONCRETE COMPARED WITH ASPHALTIC CONCRETE

Soaking Time in Jet Fuel at 140 F (hr)	Marshall Stability (lb)	
	Epoxy Asphalt Concrete	Asphaltic Concrete
0	16,400	2,650
4	14,400	665
16	15,200	Disintegrated after 6 hr
20	15,200	

Tensile Properties

In order to predict the behavior of epoxy asphalt concrete under various conditions of loading at various temperatures, a knowledge of its major mechanical properties is required. The tensile strength has been determined over a temperature range of 32 to 140 F at loading times from about 1 to 10^6 sec. Some results are given in Table 3 for EAC with 8% binder in the mix and for asphaltic concrete with 8 percent of a 60 penetration asphalt as binder. The tensile strength is rather insensitive to changes in loading time and in this respect resembles portland cement concrete much more than asphaltic concrete. Changes in tensile strength with temperature are also considerably less than those found with asphaltic concrete.

The tensile strain of epoxy asphalt concrete at fracture proved to be almost independent of the loading time and averaged about 3 percent. This tensile strain is about three times that obtained with asphaltic concrete and about ten times the tensile strain at fracture of portland cement concrete. From the tensile strength and strain measurements the stress/strain modulus at fracture has been determined over a wide range of long loading times and temperature for EAC. The insensitivity of EAC to changes in loading conditions is shown in Figure 5.

The response of EAC to dynamic loading of the type associated with moving traffic

TABLE 3

TENSILE STRENGTHS OF ASPHALTIC CONCRETE (AC) AND EPOXY ASPHALT CONCRETE (EAC)

Loading Time, (sec)	Tensile Strength (psi)					
	At 32 F		At 77 F		At 140 F	
	AC	EAC	AC	EAC	AC	EAC
4	850	2,600	130	1,000	6	140
40	570	2,000	60	620	3	120
400	310	1,500	35	470	2	100
4000	210	1,170	20	350	1	90

has been determined by studying the bending of beams of the material at various frequencies corresponding to loading times of 10^{-3} to 1 sec and temperatures from 32 to 140 F. The stress/strain modulus of the material under these short loading times varies from about 3 x 10^6 to about 10^5 psi in the temperature range 32 to 140 F. Under these conditions, epoxy asphalt concrete behaves somewhat like portland cement concrete which has a stress/strain modulus of about 3 x 10^6 psi. In the course of the dynamic testing, beams of EAC have been flexed 100 million times without fracture, indicating that the material has good resistance to failure by fatigue.

Flexural Strength

The flexural strength or modulus of rupture of pavements is an important property which characterizes their behavior under loading. This measurement has been made according to the procedure specified in ASTM methods C293-57T or C78-49 which consists of supporting a beam of standardized dimensions near the ends and producing bending by center loading at a specified rate with a testing machine. From the maximum load and the dimensions of the specimen the modulus of rupture or flexural strength is calculated. As an addition to the ASTM procedure the authors have found it very useful to measure the deflection of the beams at the center during the test by means of a dial gage. This measurement gives a good impression of the relative flexibility of various paving materials.

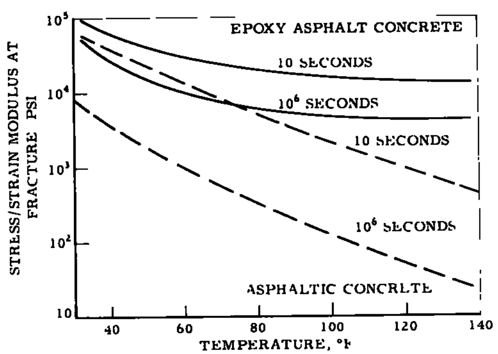


Figure 5. Dependence of stress/strain modulus of AC and EAC on temperature and loading time.

Figure 6 shows modulus of rupture and beam deflection values at maximum load for portland cement concrete, asphaltic concrete, and epoxy asphalt concrete. The beams used were 2 x 3 x 12 in. with a testing span length of 9 in. At the left of the graph the modulus of rupture of portland cement concrete is shown covering a range of about 400 to 800 psi. The center deflection of the beams at maximum load averaged 0.01 in. in these tests. Along the bottom of the graph are the data for asphaltic concrete at three levels of binder content with the modulus of rupture in the range 75 to 100 psi. The beam deflections are very large because of the flexible nature of asphaltic concrete.

The three center curves in Figure 6 show the properties of epoxy asphalt concrete at three levels of binder content; 7, 8, and 12 percent basis aggregate. The circles, triangles, and squares represent the use of three flexibilizing additives which differ in composition. The modulus of rupture of epoxy asphalt concrete may be varied from about 400 psi, which is about the lower level for portland cement concrete, to about 2,400 psi, which is two to three times that obtained with the best portland cement concrete. At the same time, epoxy asphalt concrete may be flexed to the same extent as asphaltic concrete at maximum load. Thus we have a structural material which combines the desirable properties of both rigid and flexible pavements; a strength equal to or greater than that of portland cement concrete and a tolerance for bending equal to that of asphaltic concrete.

FLEXIBLE PAVEMENT DESIGN METHODS APPLIED TO EAC

The use of epoxy asphalt concrete for structural purposes as an overlay on existing pavements or as the major structural element in a new pavement requires a thickness design procedure which takes into account the mechanical properties of the material. Most of the existing procedures for the design of flexible pavements are in reality procedures for thickness design of bases and subbases for flexible pavements, inasmuch as they take little or no account of the properties of the asphalt itself. Conventional asphaltic concrete is recognized as contributing more to the load-carrying capacity of the road than an equal number of inches of crushed rock in several methods of design whereas other design procedures consider the bituminous pavement surfacing only as a safety factor over the required design thickness of base.

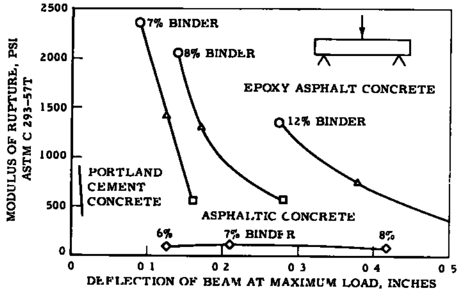


Figure 6. Modulus of rupture and flexibility of epoxy asphalt, portland cement and asphaltic concretes.

Two methods of flexible pavement design in use in this country which take the properties of the pavement surface into account in determining total required pavement thickness are the method proposed by Hveem and Carmany (8) used by the California Division of Highways, and the procedure of Palmer and Barber (9, 10) used by the State of Kansas.

Hveem-Carmany Design Method

In the California method the required thickness of pavement (T) is proportional to the tire pressure (p), the square root of the tire contact area (a), the logarithm of the number of stress repetitions (r), the horizontal pressure (Ph) observed in a Hveem Stabilometer test on the material at a vertical pressure (Pv), and inversely proportional to the fifth root of the cohesion (C) of the bituminous surfacing. The thickness design equation is

$$T = \frac{K p\sqrt{a} \ \log r \ (Ph/Pv - 0.10)}{\sqrt[5]{C}}$$

in which K = 0.0175 is a correlation coefficient bringing the equation into agreement with field experience. For convenience, the tire pressure, contact area, and number of repetitions of load are combined into a traffic index (T.I.), and the properties of the soil determined by the stabilometer test are expressed as a resistance value (R). The equation then becomes $T = 0.095\ (T.I.)\ (90-R) / \sqrt[5]{C}$. The cohesion (C) is determined at 140 F on a specimen of the compacted bituminous surfacing in the Hveem Cohesiometer, the test being roughly analogous to the modulus of rupture. The value of C increases with increasing tensile strength of the pavement surfacing and is said to be approximately equal to 45.4 times the modulus of rupture at 140 F.

In an attempt to obtain a cohesiometer value for epoxy asphalt concrete, a cylindrical core from a field installation was tested in the cohesiometer at 140 F but did not break under the maximum amount of bending which can be obtained in this apparatus. The modulus of rupture of epoxy asphalt concrete beams 2 x 3 x 12 in. containing 8 percent binder determined by ASTM method (293-57T) at 140 F was found to average 600 psi. A value of C of 600 psi x 45.4 or 27,200 is then estimated for EAC.

The thickness design equation may be conveniently solved for a given set of loading and traffic conditions and soil properties using a value of C of 100 which is characteristic of untreated gravel or crushed rock bases. The value of T obtained is the thickness of untreated granular base required over the soil involved and any combination of base and surfacing material equivalent to this thickness of gravel may be used. The gravel equivalents ($\sqrt[5]{C/100}$) for various materials given in Table 4 are those used by the State of California with the exception of the value for epoxy asphalt concrete which was determined as described previously. It will be noted that 1 in. of EAC is equivalent to 3.1 in. of gravel while 1 in. of asphaltic concrete is equivalent to 1.3 in. of gravel. Thus, 1 in. of EAC is equivalent to 2.4 in. of AC.

TABLE 4

COHESIOMETER VALUES AND GRAVEL EQUIVALENTS OF VARIOUS MATERIALS

Material	Cohesiometer Value at 140 F	Gravel Equivalent (Inches of Gravel Equivalent to 1 in. of the Material)
Epoxy asphalt concrete	27,200	3.1
Cement treated base, class A	1,500	1.7
Cement treated base, class B	750	1.5
Asphaltic concrete (85 to 300 pen. asphalt)	400	1.3
Plant mix with grade 4 and 5 cutback	150	1.1
Untreated bases and subbases	100	1.0

As an example of pavement design the authors assume a soil with an R value of 21 and determine the thickness of gravel cover with a cohesiometer value of 100 or its equivalent, required to support 19,200,000 equivalent 5,000-lb wheel loads corresponding to a traffic index of 8.7. From the equation, the thickness is calculated as 23 in. of gravel. The equivalent of 23 in. of gravel in various combinations of asphaltic concrete (AC) surfacing and crushed rock base, and combinations of epoxy asphalt concrete surfacing and crushed rock base are shown in Figure 7. For the particular loading conditions, traffic and soil properties used in the examples, it may be seen that over a 12-in. crushed rock base 3.8 in. of epoxy asphalt concrete would be required as compared with 8.5 in. of asphaltic concrete.

Two aspects of this thickness design method require some adjustment if it is to be used for EAC. First, the physical limitation of the cohesiometer in testing EAC specimens should be removed or another test method substituted for it and secondly, the validity of the correlation coefficient for EAC should be established. It seems likely that a new value of the constant would be required for each new paving material.

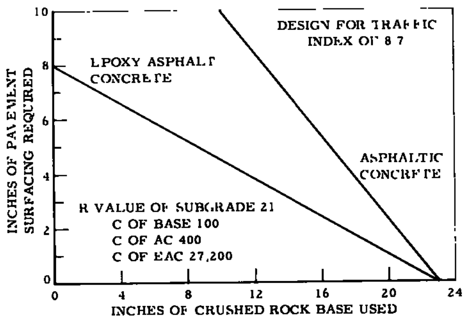


Figure 7. Thickness design of AC and EAC pavements with the Hveem-Carmany method.

Palmer and Barber Design Method

This method of flexible pavement design used by the Kansas State Highway Commission was developed by Palmer and Barber (10, 11) as an extension of the Boussinesq equations which deal with the stresses and deflections due to circular loads for a single layer case. Palmer and Barber extended the equations to include the properties of the pavement surfacing, bases and subbases, introduced coefficients taking into account the traffic volume and degree of saturation of the subgrade and substituted a modulus of deformation for a modulus of elasticity. The thickness design equation follows:

$$T = \sqrt{\frac{3Pmn^2}{2\pi ED} - a^2} \; \sqrt[3]{\frac{E}{Ep}},$$

in which T = total thickness of pavement required;
P = wheel load;
m = traffic coefficient based on volume of traffic;
n = saturation coefficient of subgrade based on rainfall;
a = radius of a circular area equivalent to the contact area;
D = deflection of the pavement surface permitted;
E = modulus of deformation of subgrade or subbase; and
Ep = modulus of deformation of pavement or surface course.

The equation gives the thickness of the pavement surfacing required if placed directly on the subgrade. If it is desired to introduce some granular base course material between the subgrade and the pavement surfacing, this is covered by

$$t_b = (T - t_p) \sqrt[3]{\frac{Ep}{Eb}}$$

in which t_b = thickness of base course;
T = thickness of pavement surfacing if used alone;
t_p = thickness of pavement surfacing when used with base;
Ep = modulus of deformation of pavement surfacing; and
Eb = modulus of deformation of base material.

If it is desired to use still a third layer of material such as a subbase, another similar calculation is required.

The values of E are determined for subgrade, base, and pavement surfacing from the stress-strain curves of triaxial compression tests. Some examples of modulus of deformation for several subbase, base, and pavement surfacing materials at room temperature as reported by the Kansas Highway Commission are given in Table 5 (HRB Bul. 8). Values of the modulus of deformation for epoxy asphalt concrete determined by the triaxial compression method (Kansas procedure) proved to be about 100,000 psi. The modulus of deformation is derived from the stress versus compression curve obtained in a triaxial compression test where the lateral pressure is maintained constant at a value of 20 psi during the test. This value of lateral pressure applied to the specimen is intended to simulate the lateral support or horizontal resistance which is normally provided by the adjacent similar material in the road. The horizontal resistance in an EAC pavement would be expected to be considerably greater than 20 psi,

TABLE 5

MODULUS OF DEFORMATION FOR VARIOUS MATERIALS FOR USE IN THE THICKNESS DESIGN METHOD OF PALMER AND BARBER

Subbase and Base Materials	Eb or Esb, psi
Coarse sand and gravel bound with soil	7,000
Fine sand and gravel bound with soil	6,000 - 7,000
Crushed limestone bound with lime dust	10,000
Chat bound with silica dust	10,000
Pavement Surfacing Materials	**Ep, psi**
Dense graded surface course, slow curing cutback	15,000
Asphaltic concrete	25,000
Epoxy asphalt concrete (triaxial)	100,000

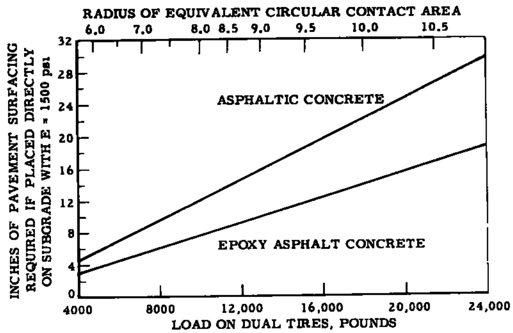


Figure 8. Thickness design for AC and EAC using the method of Palmer and Barber—surfacing placed directly on subgrade.

and a modulus of deformation of 100,000 psi for EAC determined with a 20 psi lateral pressure is thus a conservative value.

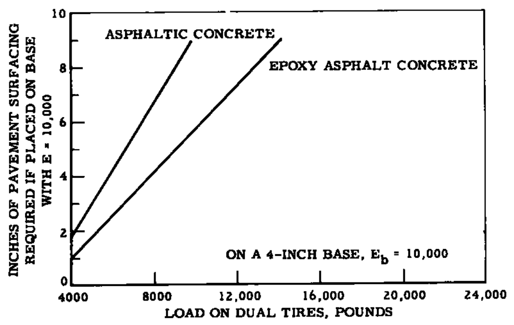
A number of examples of thickness design have been calculated for asphaltic concrete and for epoxy asphalt concrete for wheel loads on dual tires ranging from 4,000 to 24,000 lb, taking into account the variation of contact area with load. In the examples, a clay subgrade with a modulus of deformation of 1,500 psi has been assumed. A saturation coefficient of 1.0 (35 to 40 in. of rainfall per year) is used, and a traffic coefficient of 1.0 (1,200 to 1,800 vehicles per day with the design load) was applied. A deflection of 0.1 in. is permitted as has been customary in the use of this design procedure. The thicknesses of pavement surfacings required if placed directly on the subgrade are shown in Figure 8. The thickness of EAC required is about 0.6 of the thickness of AC needed according to this analysis.

When a crushed rock base of high quality (Eb = 10,000) is introduced between the subgrade and the pavement surfacing, the required thickness of surfacing is substantially reduced. Several examples of design with bases of varying thickness have been calculated, and cases involving 4- and 12-in. crushed rock bases placed on a clay subgrade (E = 1500) are shown in Figure 9 for a range of loads. The thickness requirements are reduced to realistic levels by the addition of the base, and where 4 in. of AC is called for, 2¼ in. of EAC will be required by this design procedure.

The major adjustment in this design procedure which should be made, is the use of a higher, more realistic value of the lateral pressure in the triaxial testing of the EAC specimen. Increasing this pressure would lead to some increase in the modulus of deformation of EAC which would result in a further reduction in thickness requirements.

EAC Overlays

Overlay pavements constitue a particularly appropriate use of epoxy asphalt concrete because of the variety of problems which can be solved simultaneously. From a structural point of view, 1 in. of EAC is as effective as 2 to 2.5 in. of AC and this can be of particular importance in cases where resurfacing is needed but where grade lines and drainage contours are to be held close to existing levels. In resurfacing of structures where added weight must be held to a low level, the EAC overlay gives high strength at relatively low unit weight because of the lower thickness required. When the overlay is to be used to strengthen an existing flexible pavement, the



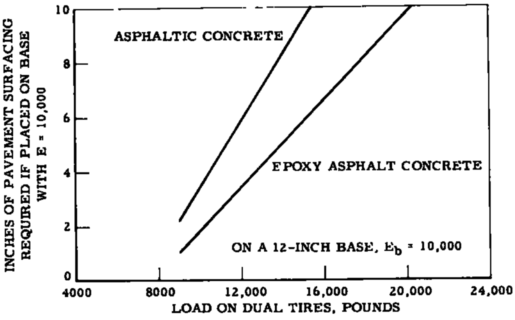


Figure 9. Thickness designs for AC and EAC on a crushed rock base—using the method of Palmer and Barber.

thickness of EAC overlay required may be estimated by the use of existing design methods. For example, the Hveem-Carmany procedure can be used in the following manner. Suppose that the number of 5,000-lb equivalent wheel loads applied to the pavement of Figure 7 is to be increased by a factor of about 10 (from 19,200,000 to 188,300,000) corresponding to an increase in traffic index from 8.7 to 11. To carry this increased load without producing shear failures in the subgrade (R value 21) a thickness of 29 in. of gravel or its equivalent is required by the design method as compared with 23 in. for the traffic index of 8.7. The additional 6 in. of gravel or its equivalent may be added in various ways. Using a gravel equivalent of 3.1 for EAC (Table 4), the job of strengthening the pavement may be accomplished by adding 6/3.1 or approximately 2 in. of epoxy asphalt concrete. Similarly, the strengthening could be accomplished with 6/1.3 or approximately 4.5 to 5 in. of asphaltic concrete. The overlay thickness design could also be accomplished in a similar manner with the method of Palmer and Barber.

Considering all of the properties of epoxy asphalt concrete, the benefits to be gained from the use of an EAC overlay include: (1) added strength and load-carrying capacity with minimum thickness; (2) resistance to shoving, rutting, or indentation under heavy loads; (3) resistance to deterioration by fuels or solvents; (4) excellent tolerance for high temperature jet blast; and (5) a joint-free, smooth riding surface.

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