Expansion and Contraction of Asphalt Concrete Mixes

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The Materials and Research Department of the California Division of Highways has been conducting a research study on the expansion and contraction of asphalt concrete mixes using aggregates ranging from nonabsorptive to highly absorptive. Data indicate that AC test specimens fabricated from absorptive aggregates and exposed to normal atmospheric conditions absorb moisture from the air which may cause considerable expansion. During the warmest hours of the day, these expanded specimens contract, causing transverse or so-called block cracking. Identical specimens kept in a dry storage cabinet did not exhibit this phenomenon. The type of cracking found in pavements appears the same as observed in laboratory specimens when both are fabricated from the same highly absorptive aggregates. Strains created in pavement by this cycle of expansion and contraction, together with deflections imposed by loads, may cause a serious reduction in service life.

This study presents data showing that expansion can be reduced by certain mineral fillers and increased by others. Expansion can also be greatly reduced by increasing the asphalt content of the mix consistent with other specification requirements.

•AGGREGATES of varying degrees of absorption are the only economical sources of road building material available in certain areas of California. Although these aggregates appear to present no great problem when used in the construction of bases and subbases, some evidence of distress is noted when they are used in the construction of asphalt concrete surfacing. Considerable mileage of pavement has been placed using these aggregates.

It can be generally stated that the California Division of Highways has had more failures and distress with asphalt concrete pavements containing absorptive aggregates than with pavements using nonabsorptive aggregates. Two main types of distress appear to be related to the degree of absorption of the aggregate. The first is drying out and raveling of the mix caused by rapid oxidation of the binder, insufficient asphalt in the mix, or the capacity of the aggregates to continue absorbing the asphaltic binder. The second is the appearance, in a few years, of excessive shrinkage cracks. On one road these shrinkage cracks, about 1 in. wide, were at right angles to the centerline and at intervals of about 15 to 30 ft. Our new test method, described later, indicated that the aggregates were highly absorptive. There was no evidence that this cracking was caused by reflection from the base. Similar cracks often appear in short sections of AC pavement which are closed to traffic pending extension by future construction.

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The most widely accepted theories of asphalt concrete pavement failures are (a) pavement fatigue (1-6), (b) excessive deflections (1, 6), (c) radius of curvature of deflected pavement (7), and (d) rapid hardening of the asphalt binder (8).

In addition to these, at least one more factor should be included, i.e., the expansion-contraction cycle of asphalt concrete mixes using absorptive aggregates.

One prime difficulty in the use of absorptive aggregates is the determination of the optimum asphalt content so that sufficient asphalt can be introduced to prevent drying out of the pavement while sufficient stability is provided to prevent rutting or shoving of the mix at the time of construction. About 20 yr ago we developed the Centrifuge Kerosene Equivalent (CKE) test (9) which provides an optimum asphalt content based on a combination of surface area and absorption. This test has given excellent service and our standard specifications contain certain limiting factors (k factors) obtained from the CKE test to eliminate or reduce the number of highly absorptive aggregates used. The CKE test is now being modified to provide separate quantitative measures of the surface area and absorbency of the aggregate. Therefore, in future specifications this determination will permit us to limit the absorption factor. A tentative limit of 0.5 percent absorption has been adopted for future specifications. A brief description of the modified CKE test is presented in this paper.

The excessive shrinkage cracking in pavements containing absorptive aggregates has been of concern to the Materials and Research Department for a number of years. Laboratory studies indicate that the most likely cause of this form of distress is absorption of moisture from the air through the asphalt film which causes considerable expansion of the pavement. When the pavement dries, contraction and cracking appear. Studies indicate that nonabsorptive aggregates do not exhibit this phenomenon. There is little doubt that strains created in the pavement by this cycle of expansion and contraction, together with deflections imposed by loads, lead to a serious reduction in service life of the pavement.

The purpose of this report is to present the development of laboratory tests for studying the expansion and contraction of asphalt concrete mixtures using absorptive aggregates during cycling under moist and drying conditions and the tentative correlation of the results with pavement performance. A method for measuring the degree of absorption of the aggregate and expansion of the mixture is outlined. Also, methods for reducing the degree of expansion are presented, together with future studies on the probable causes of these findings.

LABORATORY STUDIES

Our laboratory studies are grouped under three parts: (a) early studies on compacted AC briquettes, (b) study on compacted AC slabs, and (c) present studies on compacted AC bars.

Early Studies on Compacted AC Briquettes

In 1958 a series of AC briquettes, 3 in. high and 4 in. in diameter, were made from highly absorptive and nonabsorptive aggregates. These briquettes, made primarily for visual observation, were compacted by our kneeding compactor. Half of the specimens were compacted at 500 psi and the remaining samples at 350 psi. The laboratory test results for these briquettes are given in Table 1.

Previous data indicated that specimens compacted at 350 psi are approximately equal in density and stability to a newly compacted AC pavement, whereas a compaction pressure of 500 psi, as used in our standard laboratory procedure, produces a specimen approximately equal to the density of a pavement after a period of time under traffic.

Some of the AC briquettes made from absorptive and nonabsorptive aggregates were encapsulated in epoxy resin. We felt that by coating the briquettes, oxidation of the asphalt binder would be negligible. Therefore, any change in the hardness of the asphalt would be caused by the aggregates. Briquettes, both encapsulated and nonencapsulated, were divided into identical groups and weathered under the following conditions:

TABLE 1

TEST RESULTS—COMPACTED AC BRIQUETTES

Sample	Agg. Class.[a]	Absorp.[b] (%)	Asph. 85-100 (%)	Stability[c]		Cohesion[d]		Specific Gravity	
				350-Psi	500-Psi	350-Psi	500-Psi	350-Psi	500-Psi
57-854 (non-absorptive)	Quartsitic meta sandstone, diabase (river sand and gravel)	0.0	5.3	32	42	420	683	2.35	2.37
57-1236 (absorptive)	Volcanic dacite and rhyolite, feldspar, quartz, calcite and mica	1.0	6.3	34	38	227	312	2.07	2.09

[a]By X-ray diffraction and DTA.
[b]By modified CKE test.
[c]Stabilometer value.
[d]Cohesiometer value.

Group 1—placed on roof of laboratory exposed to normal climate;
Group 2—inserted into previously cored holes of an existing AC pavement; and
Group 3—placed in darkened cabinet.

Group 1.—During a periodic inspection of the briquettes on the roof shortly after exposure, the specimens made from highly absorptive aggregates and compacted at 500 psi showed signs of expanding. Hairline cracking and stretch marks were visible in the epoxy coating. About 3 mo from the time the specimens were placed on the roof, the first signs of cracking appeared in the epoxy coating. The other briquettes, nonabsorptive and uncoated, showed no signs of stress under the same environment. This also includes the highly absorptive specimens compacted at 350 psi. However, at the end of 6 mo, signs of distress were visible in the coating of the absorptive specimens compacted at 350 psi (Fig. 1). We believe the highly absorptive specimens compacted at 500 psi ruptured their epoxy coating before identical AC samples compacted at 350 psi primarily because of insufficient void space. The additional void space of

Figure 1. Epoxy-coated specimens, made from absorptive aggregates, exposed on roof 6 mo: left, specimen compacted at 500 psi; right, specimen compacted at 350 psi.

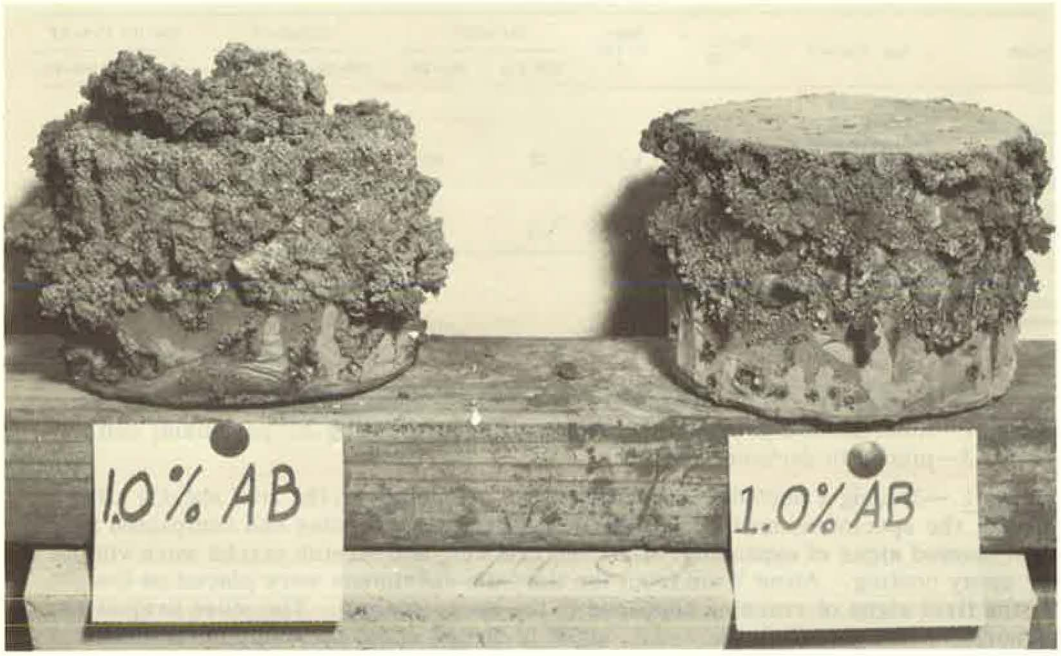

Figure 2. Same specimens as in Figure 1 after 1 yr.

Figure 3. Epoxy-coated specimens after 1 yr: left, nonabsorptive aggregate; right, absorptive aggregate.

Figure 4. Nonencapsulated specimens exposed on roof 6 mo: left, nonabsorptive aggregate; right, absorptive aggregate.

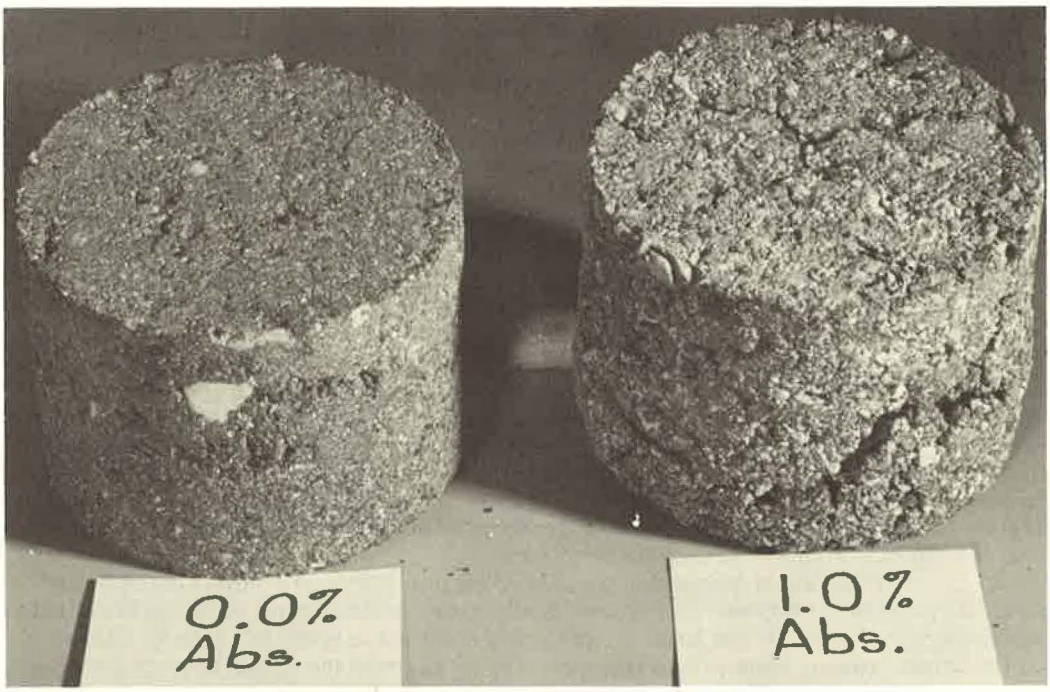

Figure 5. Same briquettes as shown in Figure 4; after 6 yr, briquette made from absorptive aggregates (1.0 percent) increased in volume 18.8 percent; no increase in volume was seen in briquette fabricated from nonabsorptive (0.0 percent) aggregate.

Figure 6. Stainless steel pins cemented to sides of specimen to measure volume changes.

specimens compacted at 350 psi permitted the absorptive aggregates to expand without bursting their epoxy coating. However, when the aggregate's volume increase became greater than the available voids in the compacted briquette, the specimens compacted at a lower pressure also ruptured.

At the end of 1 yr, the highly absorptive specimens compacted at 350 and 500 psi had completely ruptured their epoxy coating (Fig. 2), but the nonabsorptive encapsulated specimens remained in excellent condition (Fig. 3).

The nonencapsulated specimens showed the same trend. The absorptive briquettes had cracks over the entire surface, whereas the nonabsorptive briquettes had no indication of cracking. Figure 4 shows their appearance after 6 mo. After 6 yr, the diameter of the absorptive (1.0 percent) specimen increased from 4.0 in. to an average of 4.25 in. The height increased from 3.0 to 3.15 in. This is an increase of 18.8 percent in volume. No expansion in volume occurred in the nonabsorptive briquette (Fig. 5).

After noticing this volume change in the absorptive AC specimen, we made our first attempt to measure the expansion. Stainless steel reference pins, ½ in. long, were cemented with epoxy resin to the vertical sides of the test specimens made from absorptive and nonabsorptive mixes (Fig. 6). The specimens were then placed on the roof and expansion measurements were made. However, after about 1 wk, the weight of the pins and the ambient temperature caused the mix aroung the pins to soften and disintegrate. As is mentioned later, this problem was overcome by measuring the volume change of a slab and test beam specimen.

Group 2.—This group of briquettes was inserted into previously cored holes in an existing AC pavement, between and in the wheel track, to determine what visible effects the different wheel loads might have. The tightly confined briquettes, both in and between the wheel tracks, showed hairline cracking on the surface of the absorptive types. However, no signs of cracking appeared on the nonabsorptive briquettes. The surface cracking on the absorptive specimens indicates that expansion and subsequent shrinkage had occurred; apparently the force of expansion was sufficient to move the surrounding pavement slightly.

Figure 7. Absorptive and nonabsorptive AC briquettes; dark-colored specimens stored in cabinet for 6 yr, and light-colored specimens exposed on roof for 6 yr.

Group 3.—Both absorptive and nonabsorptive briquettes stored in a cabinet free from sunlight and moisture remained in excellent condition. Figure 7 shows the appearance of these specimens after 6 yr. For comparison, identical specimens stored on the roof for 6 yr are shown in Figure 5.

We had intended to recover the asphalt from the briquettes in Group 1 and determine if the absorptive aggregates harden the asphalt more rapidly. However, due to the ruptured epoxy coating, we were not able to complete this phase.

The excessive expansion of the absorptive samples and the slight or no expansion of the nonabsorptive samples weathered on the roof and in the pavement raised the following questions:

1. Why did the absorptive AC samples expand so rapidly?
2. Why did the nonabsorptive samples not expand?
3. What is the maximum expansion that can be expected from absorptive AC mixes?

In answer to the first question, we might state that there probably were microscopic holes in the epoxy coating and asphalt binder through which moisture could pass. The absorption of moisture by the aggregates caused a sufficient increase in volume to crack the epoxy coating. This destructive cycle of moisture absorption and expansion continued until the AC briquettes were completely ruptured (Fig. 2).

The absorptive briquettes which were not encapsulated (Fig. 4) had noticeable cracks over their entire surface. Their movements were not confined, allowing expansion and contraction to occur without complete rupture, which was not the case with the encapsulated briquettes.

In answer to the second question, we feel that the absence of visible signs of stress in both the encapsulated and nonencapsulated absorptive briquettes indicated that no increase in volume had occurred. We believe the moisture that did enter the briquettes was adsorbed and retained in the void spaces. The hard nonabsorptive aggregates did not absorb moisture; therefore, no overall expansion was noticed.

In answer to the third question, we may state that the maximum longitudinal expansion recorded to date on one of the test specimens (as described later) was about 0.2 in.

Study on Compacted AC Slab

To obtain better measurements, we constructed a test slab 1 ft by 2 ft by 3 in. thick. A sample of absorptive aggregate (Table 1) was mixed with 6.3 percent of 85-100 penetration paving asphalt. The aggregates and asphalt were mixed under controlled conditions in a Hobart mixer. This procedure for mixing had been calibrated previously for studies on asphalt hardening against field pug mill mixing. The slab was made in two layers and a syntron hammer was used for compaction. The specimen required about 65 lb of aggregate and was compacted to a density of 126 pcf.

After the test slab was compacted in a heavy wooden split frame, the top portion of the frame was removed and replaced with aluminum sides which permitted free expansion and contraction. The unrestrained movement was recorded by six dial indicators reading to the nearest 0.001 in. and located around the surface course (Fig. 8).

In June 1961, this fabricated slab was exposed to the outside atmosphere. Dial measurements were made every 2 hr during the working day, and the air and surface temperatures were also recorded 5 times daily.

Figure 9 shows the expansion and contraction that occurred in a 1-wk period during the study, which lasted about 3 mo. Figure 10 shows the expansion that occurred during the entire length of test. The cyclic pattern illustrates that maximum expansion for this AC mix occurs during the early morning hours when a considerable amount of moisture is in the atmosphere, and maximum contraction occurs during the warmest hours of the day. The test specimen failed to return to its original dimensions during the contraction period, probably because of structural breakdown of individual aggregates exposed to moisture during the wet cycle. The maximum expansion in width, 0.142 in., occurred on a day following a rainstorm in September, about 3 mo after the starting date of the test. This expansion would have been considerably higher if the lower wooden form had not broken under the tremendous force of the expanding asphalt concrete.

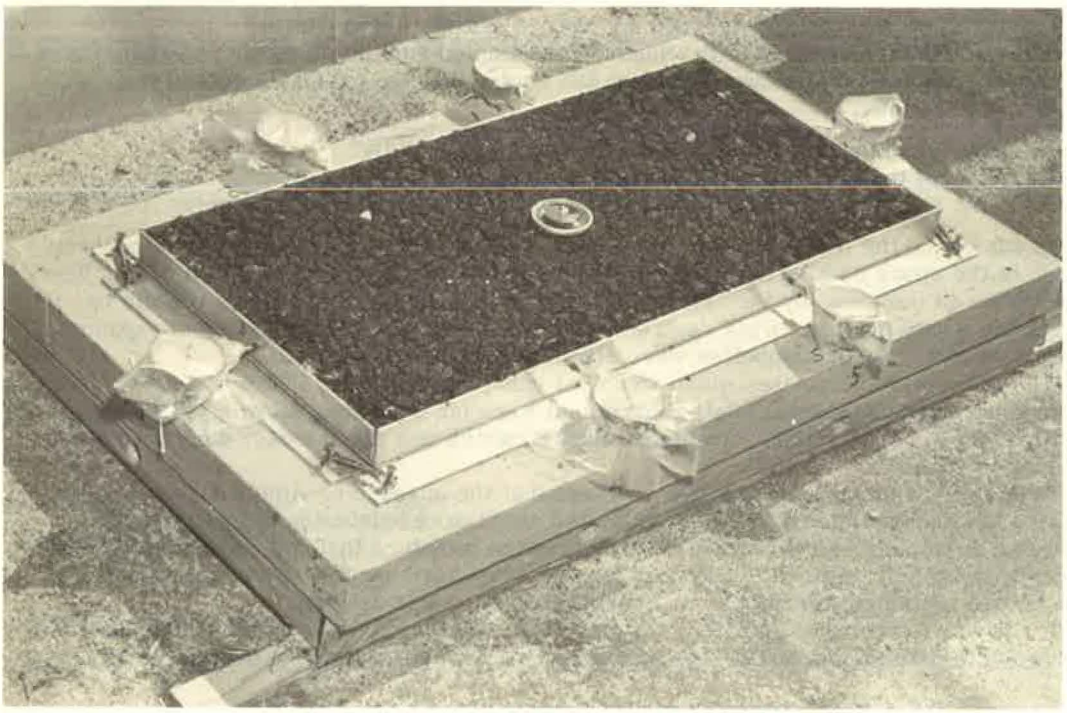

Figure 8. Slab specimen 1 ft by 2 ft by 3 in.; note springs holding aluminum sides surrounding surface course.

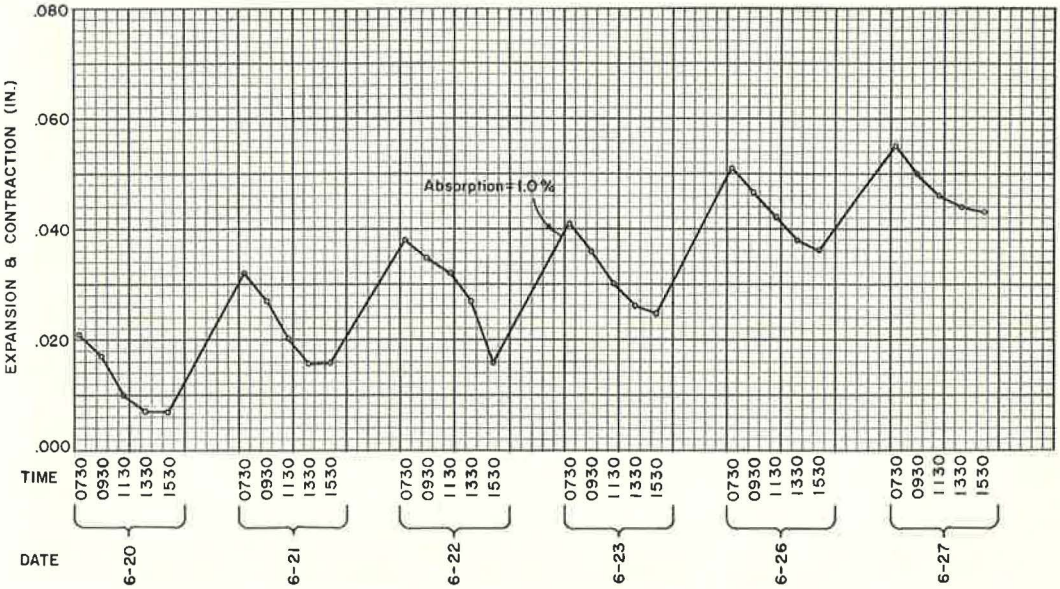

Figure 9. Test 57-1236.

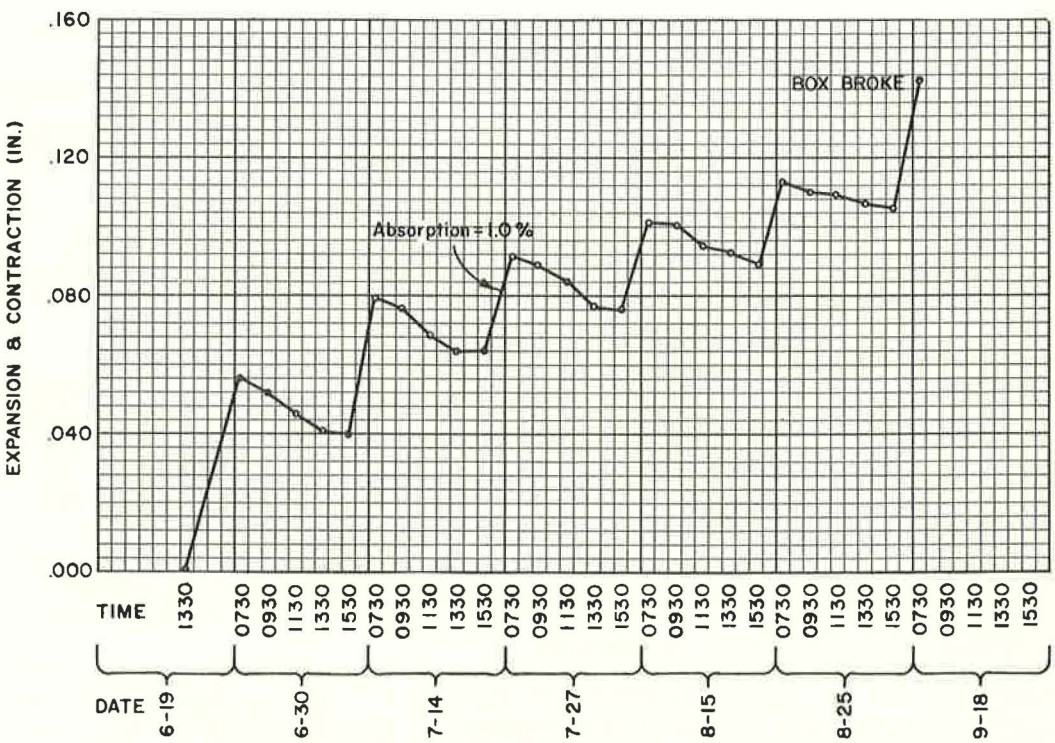

Figure 10. Test 57-1236.

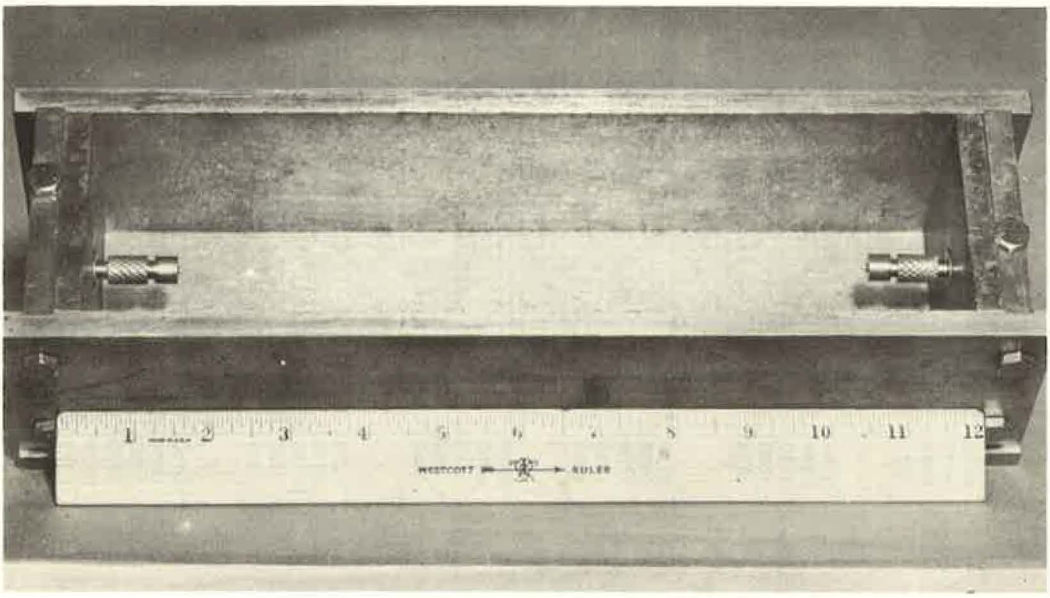

Figure 11. Steel mold, 3 by 3 by 11.25 in., for fabricating bars; note steel pins in end of plates for measuring AC bars.

The total expansion in length and width, as recorded, shows an increase in volume of 1.4 percent. However, the actual volume increase undoubtedly would have been much greater if the box had not broken and if we had arranged to determine the increase in thickness of the test specimen.

The foregoing method for fabricating AC mixes to determine the amount of expansion and contraction was discontinued for the following reasons:

1. The amount of material needed for one sample was approximately 65 lb;
2. The cost of the box and the six dial indicators for each specimen tested was considered too high; and
3. The time required for preparing one sample was excessive.

Measurement of AC Bars

To reduce the expense of constructing large test samples, a new method was adopted. Asphalt mixes were compacted into 3- by 3- by 11.25-in. steel molds (Fig. 11). Briefly, the method consists of heating the AC mixture to 230 F, rodding it into two layers in the preheated mold, and compacting it with the kneading compactor. On cooling, the mold is stripped and the steel pins at the end of the specimen are fastened into place with epoxy. The bar is cured in a 100 F oven for 3 days and then subjected to the weathering cycles, one cycle consisting of 7 days in a moist room and 7 days in a 100 F oven. Daily measurements of the specimen are made and any cracks or unusual behavior recorded. The specimen is subjected to a total of 3 to 6 weathering cycles. Detailed procedure is given in the Appendix.

Following this new procedure, test bars were made from AC samples obtained from current construction projects throughout the state, as well as from proposed aggregate sources showing varying absorptive characteristics (0.0 to 2.8 percent). Figure 12 and Table 2 present results from the first AC bars tested. These bars were fabricated from highly absorptive aggregates from two different sources.

Cracks appeared in sample 62-1863 during the drying period of the first cycle. During the third cycle, the sample expanded over 0.2 in. with block cracking throughout. This expansion of more than 0.2 in. in a 11.25-in. bar (1.8 percent expansion)

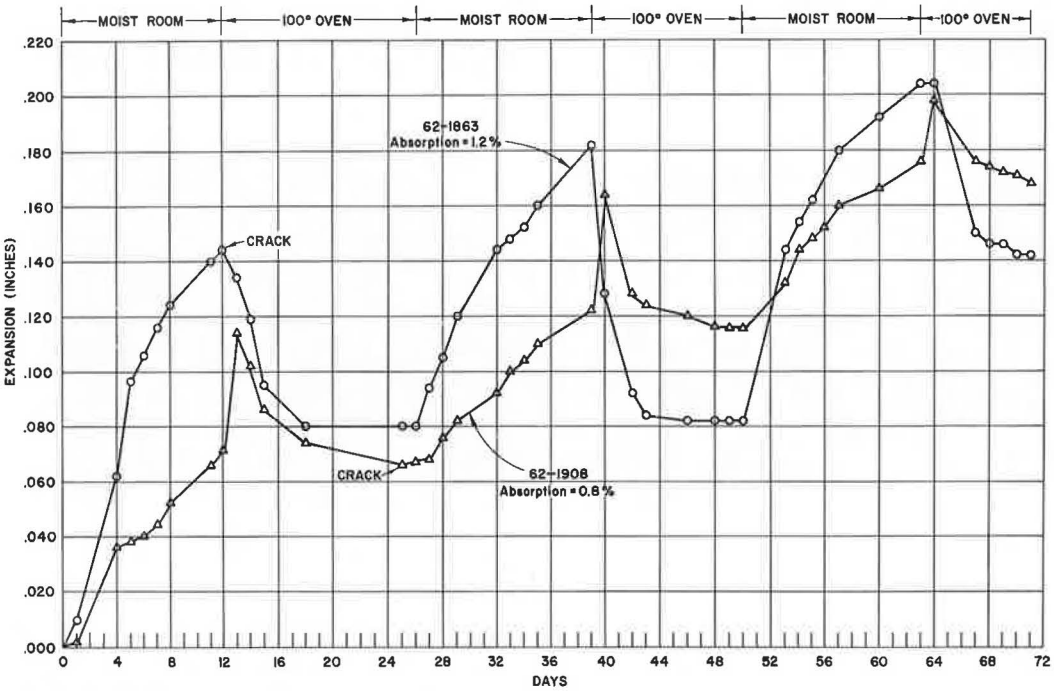

Figure 12. Tests 62-1863 and 62-1908.

is the maximum longitudinal increase recorded to date for AC bars and was reached after 64 days (Fig. 12) of exposure to wet and dry periods.

Transverse cracks were visible on sample 62-1908 at the end of first cycle (Fig. 13). Rapid expansion (0.045 in.) at the beginning of the drying cycle suggests that this specimen is susceptible to moisture in the vapor state. This sample also exhibited several transverse cracks at the end of the third cycle.

Results show sample 62-1908 required 13 days in a 100 F oven before contraction remained constant. This unusually long period was probably due to the sample's susceptibility to moisture vapor. Sample 62-1863 stopped contracting at the end of 6 days.

Data show that the average time required for maximum expansion and contraction is approximately 7 days for each wet and dry cycle.

TABLE 2

TEST RESULTS—AC BARS

Sample	Agg. Class.[a]	Absorb.[b] (%)	Asph. 85-100 (%)	Stab. Value	Coh.	Sp. Gr.
62-1863	Weathered andesite	1.2	6.9	37	255	2.11
62-1908	Weathered andesite, some tuff, minor quartz	0.8	6.5	39	279	2.13

[a]By X-ray diffraction and DTA.
[b]By modified CKE test.

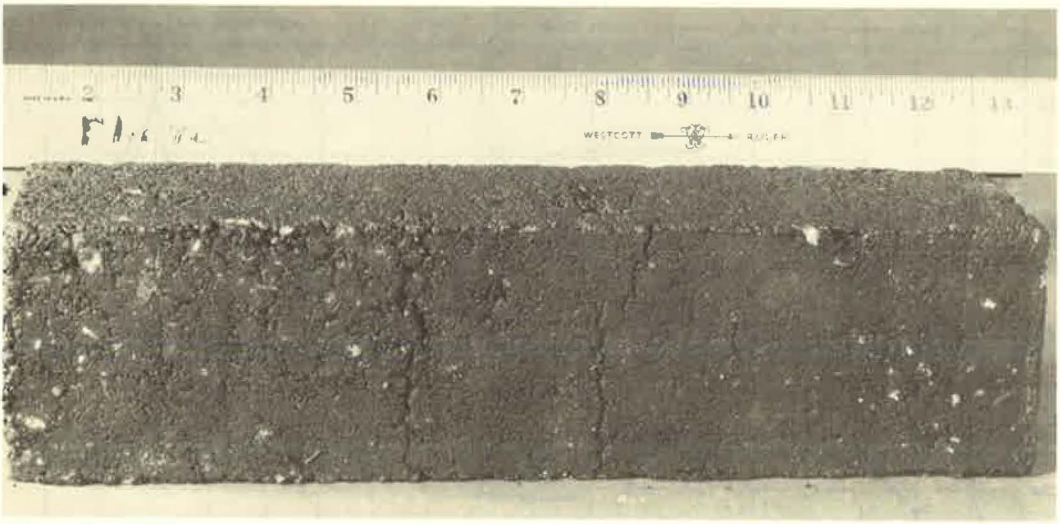

Figure 13. Test bar 62-1908; transverse cracks appeared after first cycle.

AC pavements constructed with aggregates from the same source as sample 62-1863 have shown considerable distress in the form of cracking. This aggregate source has now been eliminated for constructing AC pavements, even though the material generally passes all routine physical tests.

Figure 14 is a close-up of test bar 62-1863. Transverse cracks appeared first on the surface of the specimen, then progressed downward. At the end of the third cycle, the bar was completely block cracked.

INVESTIGATION OF PAVEMENT FAILURE

In 1962 we were asked to investigate an AC pavement failure in one of our districts. This failure (Fig. 15) consists of transverse cracks from ¾ to 1½ in. wide in the surfacing at irregular intervals ranging from 10 to 20 ft apart throughout the entire

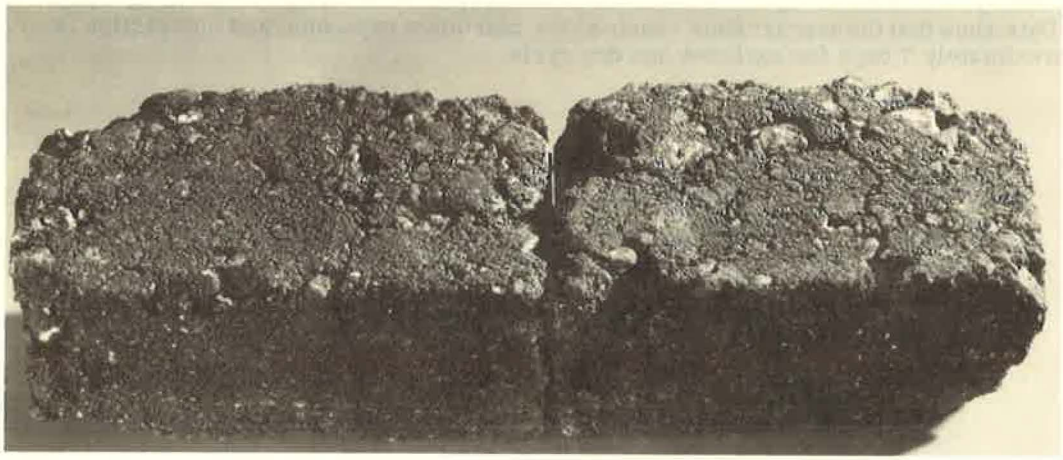

Figure 14. Test bar 62-1863, completely block-cracked at end of third cycle; ½ in. section sawed from center of test bar for microviscosity test.

Figure 15. Transverse cracks ranging from $^3/_4$ to $1^1/_2$ in. in width.

project. The pavement was constructed from aggregates obtained from a local pit.

Samples were taken from the existing pavement and from the aggregate source. Sufficient material was obtained to complete routine tests as well as expansion and contraction tests. Test results are given in Table 3.

Differential thermal analysis (DTA) of the raw aggregate indicated that the minus 200 mesh material contained nontronite (iron-rich montmorillonite) and X-ray diffraction showed montmorillonite and layered silicates.

To duplicate the field mix design, laboratory specimens were mixed in the Hobart mixer, using 6.3 percent of 85-100 paving asphalt. After mixing, the samples were compacted (see Appendix) into test bars and placed in the 100 F oven. After the specified period, the bars were placed in the moist room for the beginning of the test.

In addition, a test bar, 3 by 3 by 11.25 in., was sawed from a slab sample removed from the existing pavement. The sawed bar was dried in a 100 F oven to constant weight and then placed in the moist room for the beginning of the test.

The expansion and contraction occurring in the laboratory specimen and the AC sample bar sawed from existing pavement are shown in Fig. 16. Both AC bars show approximately the same rapid expansion in the first few hours of the dry cycle. However, the laboratory-prepared AC bar expanded more than the bar removed from

TABLE 3

TEST RESULTS—AC PAVEMENT

Samples	Agg. Class.[a]	Absorb.[b] (%)	Asph. 85-100 (%)	Stab. Value	Coh.	Sp. Gr.
From exist. pav't.	Volcanic-olivine basalt and andesite weathered, and altered feldspar montmorillonite	--	6.3	37	247	1.98
Fabricated in lab.		1.9	6.3	39	170	2.03

[a]By X-ray diffraction and DTA.
[b]By modified CKE test.

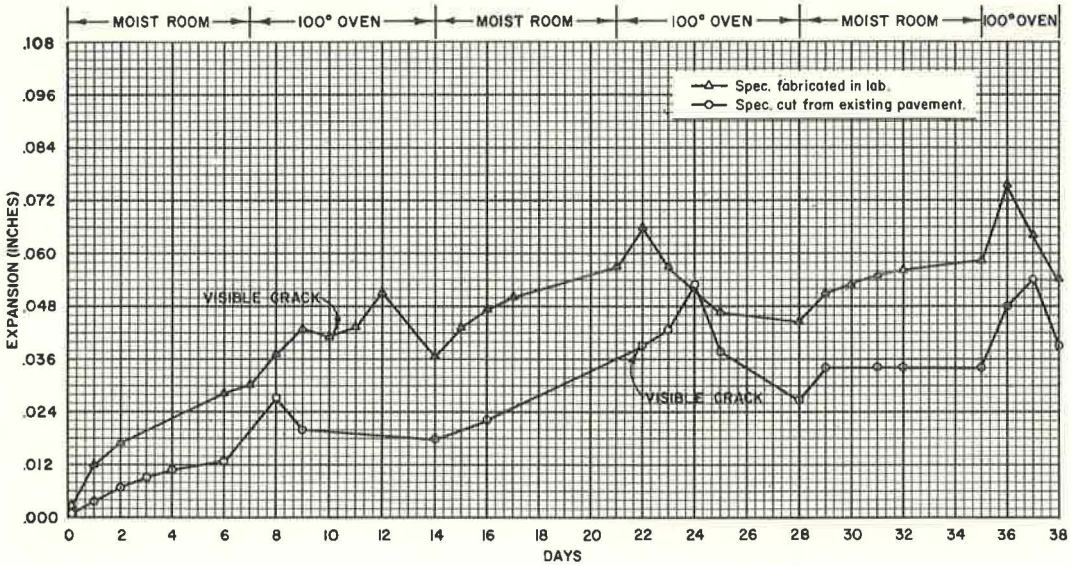

Figure 16. Test 62-5748.

the existing pavement during the wet cycle, probably because the asphalt in the latter had a longer time to be absorbed by the absorptive aggregates (both fine and course). This added depth of penetration of asphalt into the aggregates partially sealed off the pores of the aggregates and prevented it from absorbing water, thereby reducing expansion during the wet cycle.

We also felt that the expansion could be related to the type of clay (nontronite) present in the mix. To investigate this, a specimen with the clayey portion removed was fabricated. The results (Fig. 17) indicate that expansion was considerably reduced in the wet cycle. However, in the dry cycle, expansion was greater and somewhat more abrupt than it was in the regular test bar.

The smaller expansion during the wet cycle and greater expansion in the dry cycle appear to be caused by the following factors:

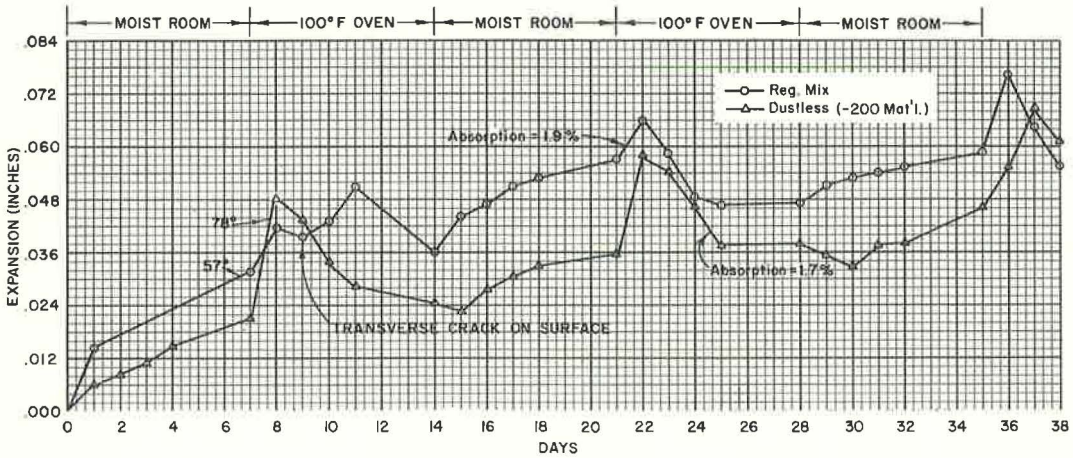

Figure 17. Test 62-5748.

1. The minus 200 material contained a considerable amount of clay (nontronite). When this expansive clay was removed from the AC mix, the total amount of expansion during the wet cycle was also reduced.

2. By wasting the minus 200 material, the natural barrier between the moisture and the larger absorptive aggregates was removed, thereby making a constant supply of water available to the larger aggregates during the wet cycle. When the dustless (minus 200 material) mix test bar was placed in the 100 F oven, the absorbed moisture entrapped in the larger aggregates attempted to escape immediately by evaporation. However, all the moisture could not escape at once through the minute interstices, and, as a result, vapor pressure rapidly built up during the first few hours of the dry cycle, causing a sharp increase in expansion.

INFLUENCE OF MINERAL FILLER ON EXPANSION

In July 1961 an experimental test section was constructed for the purpose of comparing the effectiveness of various fillers on an asphalt concrete mix. The control section was a normal AC mix conforming to our standard specifications with no commercial filler added. The results of the tests on the AC control sample, as well as on the AC sample with various fillers, are given in Table 4.

Test bars were also fabricated from the various mixtures to see whether or not expansion would occur. Two percent of three mineral fillers, A, B, and C, were used. During road construction, AC samples were taken from the paver from each section including the control section, and test bars were fabricated. Figure 18 represents the expansion and contraction behavior of the test bars.

Filler A

As shown in Figure 18, Filler A expanded excessively during the first hours of the dry cycle. This phenomenon did not occur in the AC control bar or the other AC bars with different fillers added. From results obtained, we assumed that Filler A was the contributing factor which caused this high expansion during the dry cycle. Transverse cracks appeared during the dry period of the first cycle. After cracking, the amount of expansion decreased. This usually occurs when the cracks have progressed through the test bar.

Since July 1961, five condition surveys have been made of this test section. Nine months after the completion date, transverse cracks from 1/16 to 1/8 in. in width were visible at about 10-ft intervals throughout this section. The amount of cracking, both transverse and longitudinal, have continued to increase with time. As indicated in Table 4, 132 lin ft of cracking per station was visible during the October 1963 survey.

This filler was also used in an experimental AC test section in another part of the state. This section also showed cracks appearing shortly after the pavement was completed. The aggregates, asphalt, and location were entirely different for these two projects.

TABLE 4

INFLUENCE OF FILLERS

Sample	Agg. Class.	Absorp.[a] (%)	85-100 Asph. (%)	Stab. Value	Coh.	Sp. Gr.	Lin Ft Cracks/100 Ft
Control	Granite, andesite and rhyolite	0.4	5.0	36	164	2.37	30
Filler	A	-	5.3	37	400	2.36	132
Filler	B	-	4.8	38	315	2.38	22
Filler	C	-	4.5	37	220	2.37	42

[a]By modified CKE test.

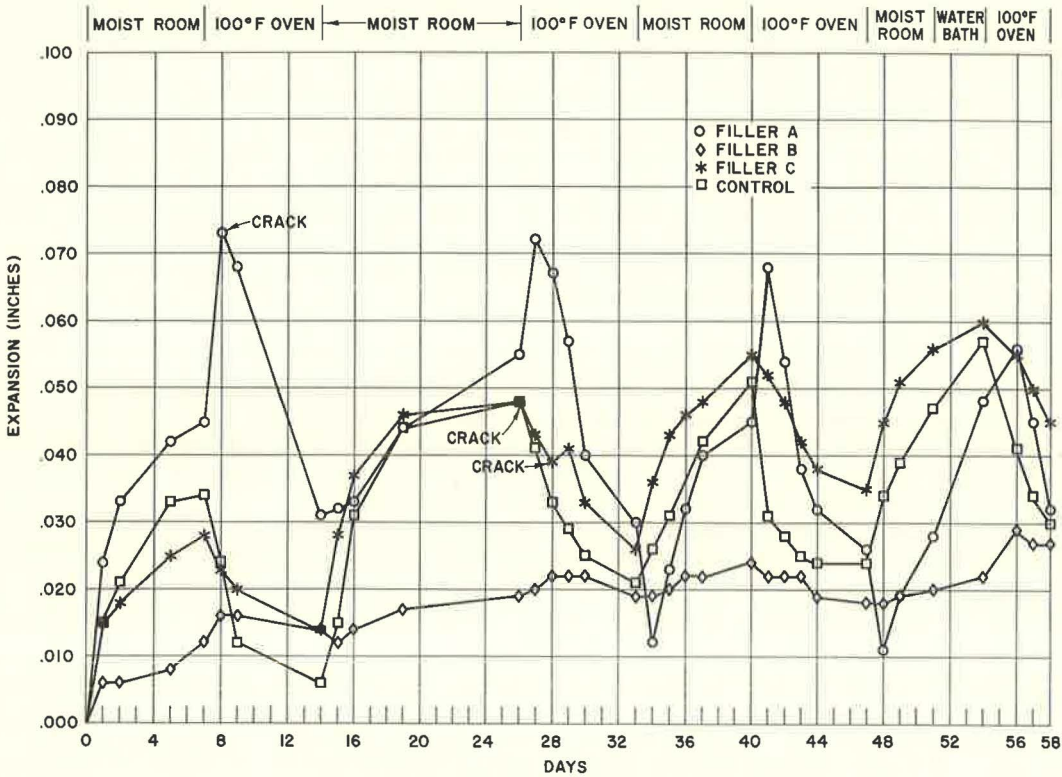

Figure 18. Effect of various fillers.

Filler B

This mineral filler reduced the maximum expansion from 0.057 to 0.029 in., or 51 percent, as compared with the control bar. No cracks were visible on the test bar after four complete cycles.

The April 1962 condition survey showed slight pitting and a few hairline transverse cracks. However, the last survey made (October 1963) showed no additional cracks or pitting since the April 1962 survey.

Filler C

This filler did suppress expansion during the first cycle but was ineffective in decreasing expansion in succeeding cycles. Cracking appeared during the drying period of the second cycle.

The pavement survey showed that excessive pitting occurred after the December 1961 survey but before the April 1962 survey. Transverse cracks were visible during the April 1962 survey, and longitudinal cracks were noticed in the October 1963 survey.

Filler B appears to be superior to the control and Filler C section, and all test sections seem to be superior to the Filler A section.

INFLUENCE OF ASPHALT CONTENT ON EXPANSION

It is the policy of the California Division of Highways to recommend the highest possible asphalt content for asphalt concrete mixes, consistent with other specification requirements such as stability. This is particularly important when using absorptive aggregates. Figure 19 shows that for a fairly absorptive aggregate, the maximum expansion was decreased from 0.049 to 0.008 in. by increasing the average asphalt

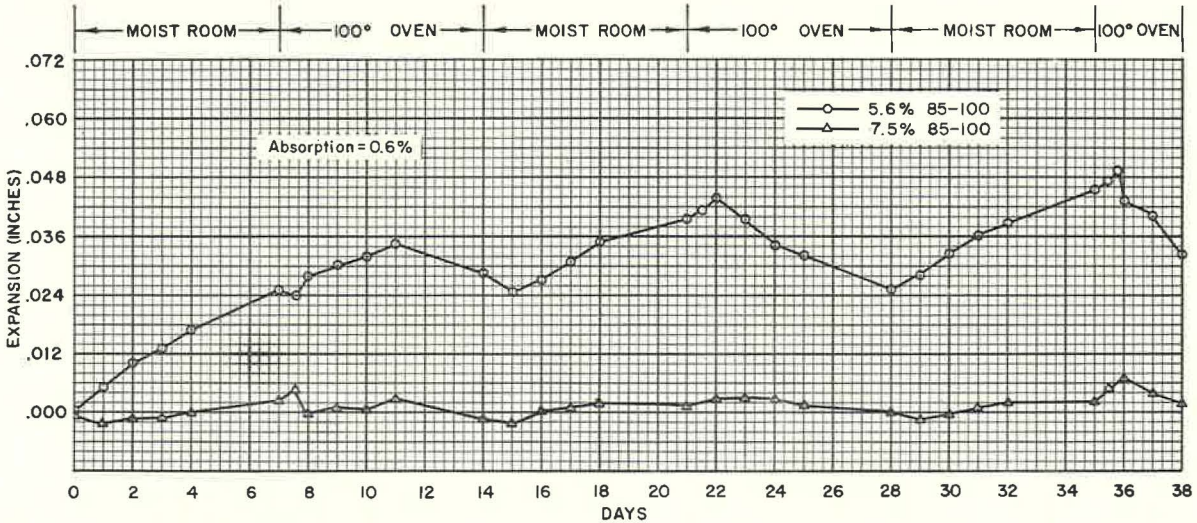

Figure 19. Test 64-1769

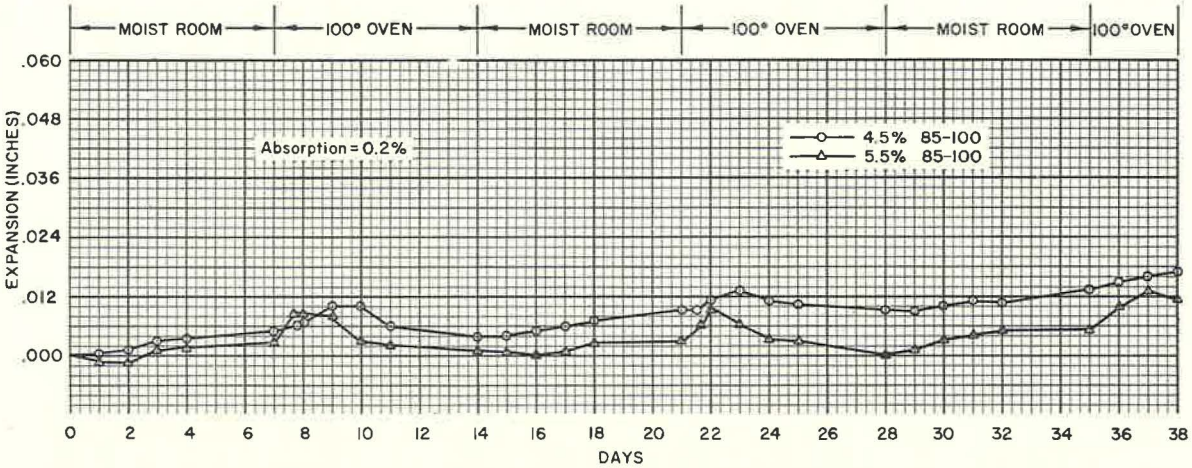

Figure 20. Test 64-1539

film thickness by 1 μ. The same increase in film thickness of a nonabsorptive or slightly absorptive aggregate will reduce the expansion only slightly, as illustrated in Figure 20.

MODIFIED CKE TEST

By modifying the CKE test, the relationship between expansion and contraction and the absorption of the aggregates used in test bars could be shown. The present CKE test is based on factors which include both surface area and absorption. Certain limits (k factors) are provided in the standard specifications to eliminate or reduce the number of highly absorptive aggregates used. This test has been used by the California Division of Highways since 1940 to indicate the amount of oil or asphalt required for a given mix and has given excellent service. The modified CKE test treats surface area and absorption of the aggregate as two distinct and separate factors. We have used this test for several years, primarily as a research tool. However, it has not officially replaced the California test method No. 303-D.

We are presently in the process of setting limiting values for absorption, and the modified CKE test will be the subject of a separate paper.

The equipment for the modified CKE test is identical to that used in the present test. Briefly, the procedure consists of placing 100 gm of the combined aggregate (up to ¾ in. maximum size) in the centrifuge cup, pouring 20 ml of kerosene over the sample, and centrifuging it immediately (within 5 sec) for a period of 2 min at 400 g. The sample is then weighed and the surface area is determined from the amount of kerosene retained. Next the sample is placed in a small pan of kerosene and is permitted to soak for 10 min. It is centrifuged again for a period of 2 min at 400 g. The sample is then reweighed and the additional amount of kerosene retained is determined. The total amount of kerosene retained minus the amount retained after first centrifuge period is equal to the absorption of the aggregate. The surface area and asphalt content are then determined from appropriate charts.

The main difference between the present and proposed CKE test procedure is that the present method involves only one centrifuging. However, the results obtained combine surface area and absorption. The modified method involves centrifuging the sample twice, thereby making it possible to obtain the true surface area and true absorption. Therefore, in future specifications, absorption can be limited and undesirable expansive aggregates can be eliminated.

FUTURE STUDIES

1. Test results have shown that some test bars fabricated from absorptive aggregates expanded as much as 2 percent longitudinally. The longitudinal and transverse pressures that these expansive mixes are capable of exerting are not known. Equipment is now being designed to measure these forces in test bars and in existing AC pavements.
2. It is proposed to determine by X-ray diffraction and DTA if there is an element, or a group of elements, which can be identified with expansive aggregates. If so, we hope to find some method to control their expansive properties.
3. To increase field-laboratory correlation studies, it is proposed that test bars be fabricated from certain preliminary AC mix designs and some construction control samples, particularly when absorptive aggregates are involved.
4. Maximum absorption values will be set on aggregates used in construction of AC mixes.

CONCLUSIONS

1. There is a relationship between the percent absorption of the aggregate as determined by the modified CKE test and the expansion and contraction of the mix. Generally, the higher the absorption, the greater is the expansion.
2. Maximum expansion usually occurs during the wet cycle. However, several figures show maximum expansion occurred during the first 24 hr of the dry cycle.

3. Maximum contraction occurs during the dry cycle.
4. AC test bars generally continue to expand during the test cycle and usually do not return to their original length.
5. Inherent strains are capable of cracking test bars without the aid of external forces.
6. Tests to date show that expansion can be reduced by removing expansive clays from the aggregate mix.
7. Tests indicate that an increase in asphalt content usually reduces expansion in the wet cycle.
8. Expansion can be reduced by some mineral fillers, but other fillers may encourage expansion.
9. An ideal expansion suppressor would be a filler, natural or manufactured, which would absorb the moisture entering into the AC pavement without increasing in volume.
10. Studies made to date show good correlation between expansion bars and actual pavement conditions.
11. A new test procedure has been presented which will aid the engineer in making a more prudent analysis of the aggregates to use in the construction of AC pavements.

There are still many unanswered questions concerning the causes and effect of expansion and contraction. We feel, however, that when this study is completed, the information gained will increase understanding of AC pavement failure. With the causes of certain types of failures known, we feel that corrective measures can be taken.

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Appendix

PROCEDURE FOR FABRICATING 3- BY 3- BY 11.25-IN. ASPHALT CONCRETE BARS

1. Place approximately 4,000 gm asphalt concrete mixture in a 230 F oven for at least 2 hr.
2. Into a 3- by 3- by 11.25-in. steel mold (Fig. 21) preheated to 140 F, place sufficient asphalt concrete mix to fill the mold one-half full.
3. Rod the mix 20 blows with a $^3/_8$-in. diameter bullet-nosed rod (Fig. 22).
4. Add sufficient material to fill the mold.
5. Rod second lift 20 blows. (Be sure mix is well rodded around end pins.)
6. Compact specimen for 5 min at 15-lb pressure on the dial of the kneading compactor (125 psi) (Figs. 23 and 24).
7. Continue compaction for an additional 5 min at a pressure of 31 lb on the dial of the kneading compactor (250 psi).
8. Place steel plate ($2^7/_8$ by $^1/_4$ by 11 in.) on specimen and compact for 2 min at the 31-lb pressure for leveling-off load (Fig. 25).
9. Strip mold from specimen and place compacted specimen on sheet of plywood (Fig. 26).
10. Secure steel end pins to test specimen with epoxy resin (Fig. 27).
11. Leave specimen in 100 F oven for approximately 63 hr.
12. At the start of the test, record length of AC bar and place bar in moist room. Make and record measurements.
13. After 7 days in the moist room, place the AC bars in the 100 F oven. Make measurements every 2 hr.

Figure 21. Mold and carriage which holds steel mold during compaction.

Figure 22. AC mix being rodded with $^3/_8$ in. bullet-nosed rod.

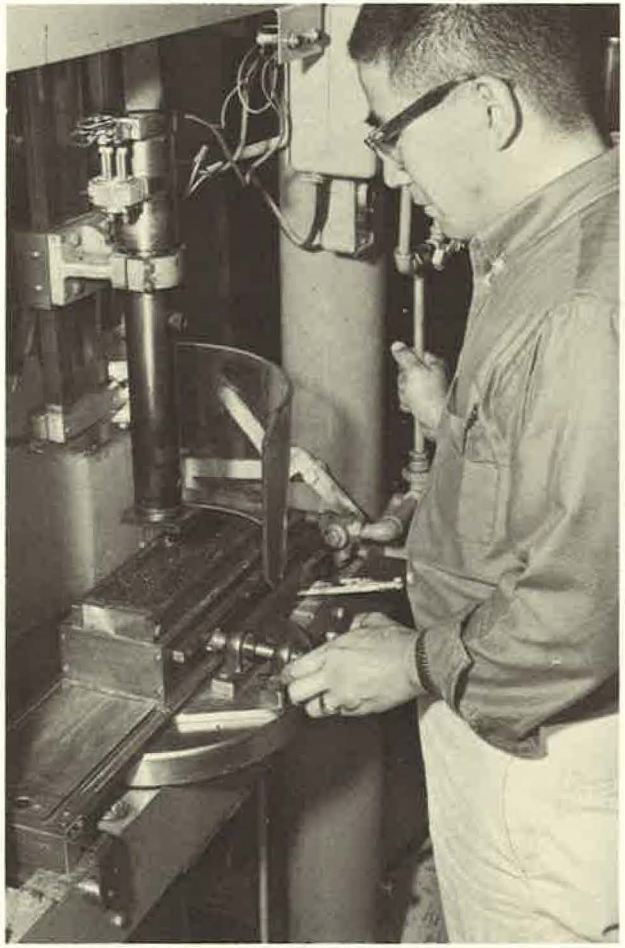

Figure 23. AC mix ready to be compacted with 2- by 3-in. rectangular compacting foot (2 by 3 in.).

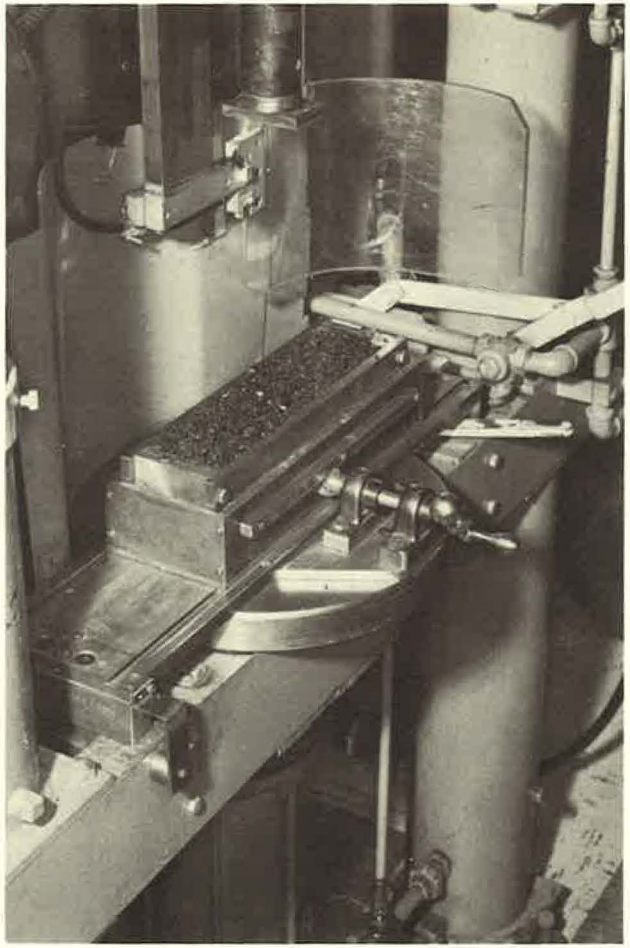

Figure 24. AC bar being fabricated; crank is turned $\frac{1}{4}$ rev after each stroke of compactor foot.

Figure 25. AC bar receiving leveling-off load.

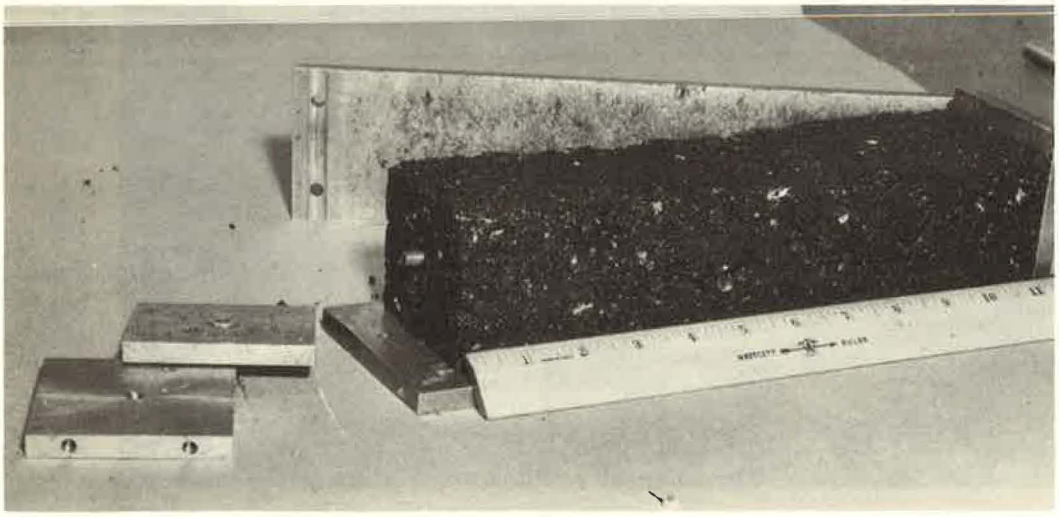

Figure 26. Metal mold being stripped from AC bar, showing steel pins used for measurement.

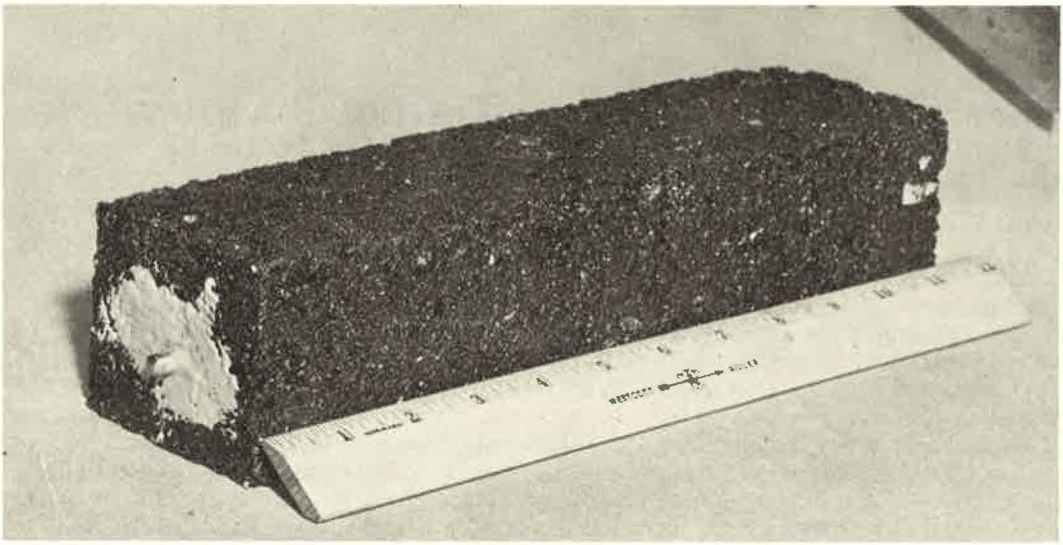

Figure 27. Finished AC bar showing steel pins secured into bar with epoxy.

14. After the first 8 hr in the 100 F oven, make measurements once a day for the remainder of the 7-day period. Then place the specimen again in the moist room and begin the second cycle. Continue this for three cycles, or in some special cases, six cycles. (One cycle equals 7 days in the moist room and 7 days in 100 F oven.)