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16. ABSTRACT
Most bituminous pavements are prone to exhibit some form of cracking during their service life. The reasons or causes of this cracking appear to be as varied as the type and pattern of the cracks themselves. To the engineer familiar with this type of pavement, the basic cause of the cracking is often readily identifiable; however, in some instances the causes or reasons are much more elusive and complex. Eliminating any cracking of the surface course caused by a structural deficiency of the underlying supporting material, some of the most commonly accepted causes of cracks appearing in asphalt pavements are:

1. Shrinkage cracks caused by temperature variations in the asphalt binder.
2. Reflection cracks in overlays caused by transmission of cracks from the underlying layer, such as bituminous overlays of old PCC pavements.
3. Cracks caused by expansion and contraction of the underlying soil, for instance if a pavement were placed directly on a clayey-type native soil.
4. Cracks due to oxidation of the binder which causes the pavement to become hard and brittle and unable to withstand even comparatively small deflections.
5. Cracking due to high shear susceptibility of the asphalt binder, resulting in contraction cracks.

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CRACKING OF ASPHALT CONCRETE PAVEMENTS ASSOCIATED WITH ABSORPTIVE AGGREGATES

By

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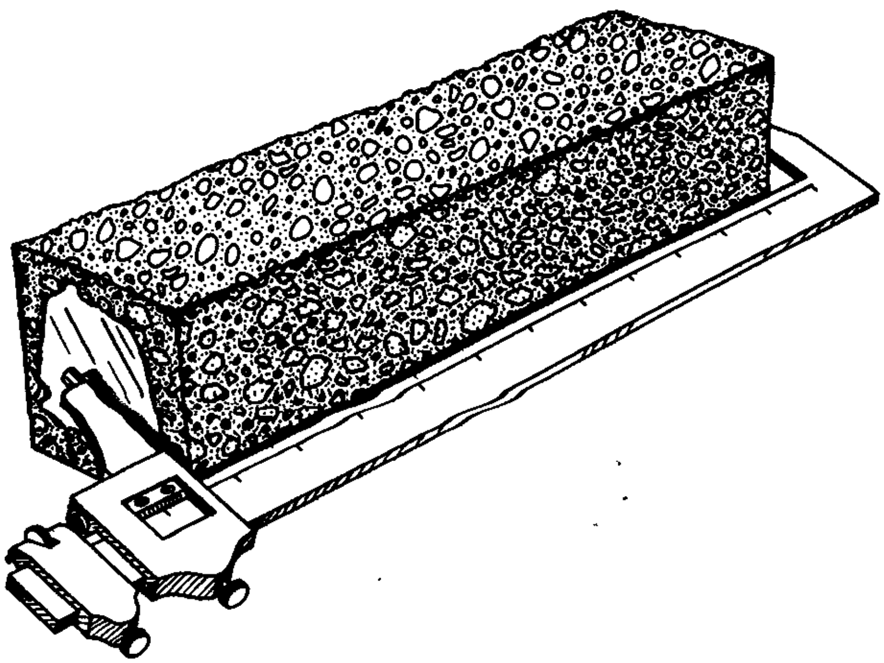
Assistant Materials & Research Engineer



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of the Association of Asphalt Paving Technologists

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February 1966

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RESEARCH REPORT

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Ernest Zube*

INTRODUCTION

Most bituminous pavements are prone to exhibit some form of cracking during their service life. The reasons or causes of this cracking appear to be as varied as the type and pattern of the cracks themselves. To the engineer familiar with this type of pavement, the basic cause of the cracking is often readily identifiable; however, in some instances the causes or reasons are much more elusive and complex. Eliminating any cracking of the surface course caused by a structural deficiency of the underlying supporting material, some of the most commonly accepted causes of cracks appearing in asphalt pavements are:

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2. Reflection cracks in overlays caused by transmission of cracks from the underlying layer, such as bituminous overlays of old PCC pavements.

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3. Cracks caused by expansion and contraction of the underlying soil, for instance if a pavement were placed directly on a clayey-type native soil.
4. Cracks due to oxidation of the binder which causes the pavement to become hard and brittle and unable to withstand even comparatively small deflections.
5. Cracking due to high shear susceptibility of the asphalt binder, resulting in contraction cracks.

A great many papers have been written discussing these causes of cracking and methods for their prevention. At the annual 1965 meeting of the Highway Research Board(1), the writer presented a paper which presented a rather new concept of bituminous pavement cracking which is associated with volume changes involving the more absorptive aggregates, particularly in the presence of moisture. The present paper deals with further aspects of this problem.

In the construction of thousands of miles of asphaltic pavements in the California Highway System, essentially all of the common types of aggregates known to road builders have been used. These aggregates range from hard durable ones, to the relatively soft, highly absorptive types.

Although the grading of the mixes produced from these aggregates are similar, the percentage of asphalt required for a durable and stable pavement varies markedly according to their absorptive capacity. This absorptive capacity is determined by a modification of our presently used CKE method(2) which has been utilized for over 20 years and has given excellent results. Whereas our present test procedure makes a combined allowance for asphalt absorption and surface roughness, the new modified method will provide separate qualitative measures of the surface area and absorptiveness of the aggregate. It can be stated that, generally, asphaltic concrete surfaces constructed with absorptive aggregate have shown more distress than mixes constructed from hard nonabsorptive aggregate. Abson recovery tests made on the extracted asphalt showed, as a rule, more hardening of the asphalt binder in absorptive aggregate through syneresis and oxidation than in nonabsorptive aggregates.

In order to study this phenomenon in more detail, a research project was initiated in 1958. A number of AC briquettes 3" high and 4" in diameter from highly absorptive and also nonabsorptive aggregate were fabricated. The amount of asphalt used varied according to the absorptive qualities of the test aggregates and was determined in accordance with our asphalt determination procedure[2] for State highway projects. Specimens were compacted by our kneading compactor.

In order to eliminate or hold to a minimum oxidation of the asphalt binder, some of the briquettes of both absorptive and nonabsorptive aggregates were incased in epoxy resin. An equal number of specimens were left uncoated. The specimens were then randomly divided. Some of both types were placed on the roof of the laboratory while others were placed in a darkened cabinet maintained at room temperature. All specimens were inspected periodically.

<u>Effect of Roof Storage</u>

Shortly after exposure on the roof top of the laboratory, the specimens fabricated from the absorptive aggregate showed signs of expansion as indicated by hairline cracks and stretch marks. After three months' exposure, the first signs of actual cracking appeared in the epoxy coating. The other coated briquettes fabricated from nonabsorptive aggregates, however, revealed no signs of stress.

After one year's exposure the highly absorptive specimens had completely ruptured the epoxy coating, while the nonabsorptive capsulated specimens remained in excellent condition (Figure 1).

The specimens that were left uncoated showed the same trend. The absorptive briquettes had cracked over their entire exposed surface, whereas the nonabsorptive briquettes showed no signs of distress (Figure 2).

The specimens were left on the roof exposed to the elements for a period of six years. During this period the absorptive aggregate briquettes increased in diameter from 4.0" to 4.25" and in height from 3.0" to 3.15". This amounted to a total volume increase of about 19%.

Effect of Cabinet Storage

The absorptive and nonabsorptive aggregate specimens stored in a cabinet at room temperature in the laboratory building free from sunlight and moisture for a period of six years remained in excellent condition. In comparison, identical specimens stored on the roof are shown in Figure 3.

It was our original intention to recover the asphalt from both absorptive, nonabsorptive, capsulated, and non-capsulated specimens for quality tests including several of our recently developed tentative test methods for paving asphalts(3). However, due to the complete rupture of the epoxy coating, we were not able to complete this phase of the work.

Measuring Volume Change

Upon observing the volume changes in the briquettes fabricated from absorptive aggregate, an attempt was made to measure the amount and, possibly, the forces involved in the expansion. Three different methods have been tried. At first, stainless steel pins were cemented to the sides of the briquettes. This technique proved to be unsuccessful and was therefore abandoned.

A second trial method consisted of the measurement of the expansion and contraction of AC slabs by means of Ames dials.

The third and presently used method for measurement of volume change consists of the fabrication of small bars which are subjected to regular curing cycles. Change in length is measured and recorded daily.

The second method was successful but was also eliminated as it proved to be too cumbersome and uneconomical. However, this procedure may be of interest to some researchers and a short description of the method is presented below.

Study on Compacted AC Slab Specimens

To obtain measurements of volume change a test slab 1' x 2' x 3" thick was fabricated. An absorptive aggregate (1% absorption) was mixed with 6.3% of 85/100 penetration paving asphalt (by weight of the dry aggregate). The aggregate and asphalt were mixed under control conditions in a Hobart mixer which was previously calibrated against field pugmill mixing. The slab was compacted to a density of 126 lbs. per cu. ft. in two layers using a Syntron hammer for compaction. The specimen required 65 lbs. of aggregate.

The test slab was compacted in a heavy wooden frame. After compaction, the top portion of the sides was removed and replaced with free moving aluminum sides which permitted unrestrained expansion and contraction of the specimen. The unrestrained movement was recorded by six dial indicators (reading to the nearest .001") located around the surface as shown in Figure 4.

This slab was exposed to the outside atmosphere in the early summer of 1961. Dial readings and temperature measurements were made five times daily. Figure 5 shows the expansion that occurred in a three month test. The cyclic pattern shows that maximum expansion occurs during the early morning hours when there is a considerable amount of moisture in the air. Maximum contraction occurs during the warmest hours of the day. It is noteworthy that the specimen failed to return to its original dimension during the contraction period, possibly due to aggregate breakdown during the moisture cycle. The maximum expansion of 0.142" generated sufficient force to break the frame. This occurred soon after an early unseasonable rainstorm.

Subsequently, two additional similar slabs were fabricated. One, with nonabsorptive aggregate, showed a maximum expansion of 0.020" after two years' exposure. The third slab was constructed from highly absorptive aggregate (2.8%). The box and frame broke immediately after exposure to rain. No readings were obtained. As mentioned before, this method of fabricating test sections was also abandoned as it proved to be cumbersome and uneconomical.

Fabrication of AC Bars

Because of the expense and time involved in fabricating the large slab specimens, a new method, still currently in use, was adopted. It consists of compacting the AC mix into 3" x 3" x 11.25" long steel molds (Figure 6) using our kneading compactor. (For details of fabrication see Reference 1.) After cooling, the mold is stripped and the steel pins at the ends of the compacted bar are fastened with epoxy. The bars are then cured at 100°F for three days before being subjected to the weathering cycles. Each weathering cycle consists of seven days in the moisture room followed by seven days drying in a 100°F oven. The specimens are subjected to from three to six weathering cycles during which daily measurements and observations are made. The measurements are made with a micrometer to the nearest 0.001" as shown in Figure 6.

Figure 7 represents results from AC bars tested by this method. The 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 had expanded over 0.2" and was cracked throughout its entirety. This expansion (0.2" in a 11.25" bar or 1.8%) is the maximum longitudinal increase recorded to date for AC bars. This condition was reached after 64 days' (Figure 7) exposure to wet and dry periods.

Transverse cracks were visible on Sample #62-1908 at the end of the first cycle (Figure 8). Rapid expansion (0.045") at the beginning of the drying cycle would indicate that this specimen was susceptible to moisture in the vapor state. Subsequently, several transverse cracks were observed at the end of the third cycle. This specimen required 13 days in the 100°F oven before contraction became constant which, as stated, was probably due to its susceptibility to moisture vapor. Our data indicate that the average time required for maximum expansion and contraction is approximately seven days for each wet and dry cycle.

AC pavements constructed with aggregates from the same source as Sample #62-1863 have shown considerable distress in the form of cracking even though this material generally passes all routine physical laboratory tests. At the end of the third cycle the bar was completely cracked.

Investigation of Pavement Failures

Eagle Lake Project

Pavement distress consisting of excessive transverse cracks developed in the surfacing of this roadway. Consequently, the Materials and Research Department was requested to investigate and, if possible, determine the causes of this cracking.

The transverse cracks in the surfacing (Figure 9) vary in width from 3/4" to 1½" and were found at intervals ranging from 10 to 20 feet throughout the entire project. The pavement was constructed from aggregates obtained from a local pit.

Tests were made on samples obtained from the aggregate source and also from the existing pavement. Results are shown in the table below.

Samples	Agg. Class. (X-Ray&DTA)	% Absorb. (Mod CKE)	% Asph 85-100	Stab Value	Coh.	Sp. Gr.
From exist. pav't.	Volcanic-Olivine Basalt&Andesite weathered, & altered Feldspar Montmorillonite	--	6.3	37	247	1.98
Fabricated in lab.		1.9	6.3	39	170	2.03

Differential Thermal Analysis (D.T.A.) Tests on the raw aggregate indicated that the minus 200 mesh material contained Nontronite (Iron rich Montmorillonite). The X-Ray Diffraction Analyzer revealed Montmorillonite and layered silicates.

To duplicate the field mix design, laboratory specimens were mixed in the Hobart mixer using 6.3% of 85/100 paving asphalt. After mixing, the samples were compacted into test bars and placed in the 100°F oven. After the curing period, the bars were placed in the moist room for the beginning of the test.

In addition, a test bar 3" x 3" x 11.25" 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.

A record of the expansion and contraction occurring in the laboratory-fabricated specimen and the AC sample bar sawed from existing pavement is presented graphically by Figure 10. Both AC bars showed approximately the same rapid expansion in the first few hours of the dry cycle. However, the laboratory-prepared bar expanded more during the wet cycle, probably due to the fact that the asphalt in the specimen from the existing pavement had a longer time to be absorbed by the absorptive aggregates (both fine and coarse). This added depth of penetration of asphalt into the aggregates partially sealed off the pores of the aggregates and prevented it from absorbing water thus reducing expansion during the wet cycle.

It was suspected that the expansion could be related to the type of clay (nontronite) present in the mix. In order to examine the effect of nontronite clay on the expansive properties of the test bars, a specimen with the clayey portion removed was fabricated. The results indicate that expansion was considerably reduced in the wet cycle. However, in the dry cycle, expansion was greater and somewhat more abrupt than in the regular test bar during the first few hours.

Possible reasons for the greater degree of expansion in the dry cycle are:

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 for keeping the moisture away from the larger absorptive aggregates is removed. Removal of this natural water barrier offers the larger aggregates a constant supply of available water during the wet cycle. When the "dustless" (minus 200 material) mix test bar was placed in the 100^{o}F oven, the absorbed moisture entrapped in the larger aggregates tended to escape immediately by evaporation. However, since evaporation was restricted by the minute

interstices, vapor pressure built up rapidly during the first few hours of the dry cycle causing a sharp increase in expansion.

Likely Project

Recently another AC surface was to be constructed in the same general area as the above-mentioned project. The pavements previously constructed in this vicinity with local aggregates have had a poor service performance. Typical surface distress has been in the form of transverse cracks and ravelling of the mix. Our routine tests did not conclusively show why these pavements cracked after a comparably short period under traffic. However, results from our expansion tests did show this material to be highly expansive.

In order to reduce AC expansion on this project, we tried hydrated lime as a filler and a lime slurry for precoating the aggregate prior to mixing with the asphalt. This slurry treatment had been successfully used by the Texas Highway Department in certain areas exhibiting failure problems.

Using the local aggregate, preliminary test bars were fabricated. The aggregate showed 0.6% absorption and 5.6% asphalt of 85/100 penetration was used. After 6 cycles, the bars showed the following expansion:

	% Filler	Max. Exp.
Control	0	0.050"
Hyd. Lime Dust	2.0%	0.045"
Lime Slurry	1.0%	0.030"
Lime Slurry	2.0%	0.024"

The hydrated lime, when added as a filler, did not prove beneficial for this particular aggregate. However, when applied in a slurry form, a marked reduction in expansion was noticed (see Figure 11).

This project was actually constructed in Sept.-Oct. 1965 utilizing the lime slurry treatment. Besides the control section (no treatment) two test sections with 1.25% and 1.75% lime, in a slurry form, were placed. The lime (% by dry weight) was mixed with water to a creamy consistency. The slurry was then added to the aggregate in a small pugmill which discharged onto the belt carrying it to the dryer.

Bars have been fabricated from all three field mixes. Also, additional bars were sawed directly from the compacted pavement. These bars have just been subjected to the test cycles. It is too early to draw any conclusions although the bars fabricated from the untreated mix have shown considerably more expansion than the lime treated material.

Methods to Eliminate or Minimize Expansion and Contraction With Resulting Cracking of the Surface

Our experience so far has revealed two methods to minimize expansion of the bars. These are the addition or elimination of certain mineral fillers and adjustment of the percentage and grade of paving asphalt used.

Mineral Fillers

An experimental test section for evaluating the effectiveness of mineral fillers was constructed in 1961. The control section was a normal AC mix conforming to our Standard Specifications without the addition of any commercial filler. The mix in three other test sections each contained commercial fillers.

The mineral fillers and percentage used were:

1.	Filler A	(Fibrous type)	2%
2.	Filler B	" "	2%
3.	Filler C	(Calcarous type)	2%

During road construction, AC samples were taken from the paver in each section including the control section from which test bars were fabricated.

Following is a discussion of the results of tests on the AC bars and the findings of the condition surveys of the pavement test sections:

Filler A

Excessive expansion accompanied by transverse cracks occurred in the bar during the first cycle. After cracking, the amount of expansion decreased.

Six condition surveys have been made of this test section. The amount of cracking has steadily increased with time. In the last survey of January 1965, 138 lineal feet of cracking per station was recorded. The general condition of this section is fair.

This mineral filler was also used in an experimental asphalt concrete test section in Contra Costa County with similar results. Here also, transverse cracks appeared shortly after the pavement had been completed. It might be added that the source of aggregates and the climatic conditions were entirely different for these two projects.

Filler B

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

Transverse cracking increased from 3.5 feet in October 1961 to 27.5 lineal feet per station in April 1962. From April 1962 until the final survey, January 1965, no additional cracking has appeared. This section is in excellent condition.

Filler C

This filler suppressed expansion during the first cycle. Succeeding cycles, however, showed this additive ineffective in decreasing expansion. Cracking appeared during the drying period of the second cycle.

Twenty lineal feet per station of hairline transverse cracks were recorded in the October 1961 survey. The amount of cracking has steadily increased to 48 lineal feet per station as reported in the January 1965 survey. The cracks now range from hairline to 1/8" in width.

The general condition of this section is good.

Control Section

Transverse cracks ranging from hairline to 1/16" in width were visible in October 1961 when the first condition survey was made. Since that date the increase in transverse cracking has been slight. The lineal footage of cracking recorded in the January 1965 survey was 36' per station. This section is in very good condition.

To summarize the results of this investigation, we feel that Filler B was effective in reducing expansion and contraction of the pavement. However, this phenomenon may not necessarily hold true for other aggregates. Figure 12 shows the cyclic expansion-contraction for Fillers A and B for a period of 58 days.

A further example of the influence of various types of fillers on expansion was provided by a recent series of tests on a sample of asphalt concrete from a going contract. As a routine procedure, an expansion test bar was fabricated. At the end of 6 weathering cycles, the test bar had expanded .090" and cracks were visible on the surface (Figure 13). We then obtained samples of the aggregate and asphalt used on the project, added different fillers and fabricated additional test bars. 5.5% asphalt was used on the job site. The aggregate showed 0.5% absorption. Three fillers were tested, Kaolin, a powdered fibrous type, and a hydrated lime. After 6 complete weathering cycles, we were able to reduce the maximum expansion as shown in the following table:

Fillers	% Filler	% Asph. 60-70	Av. Micron Film Thick.	Stabs.	Max. Expan. After 6 Cys.
Control	---	5.5	3.1	48	.090"
Kaolin	2.0	5.4	3.1	44	.024"
Kaolin	2.0	7.0	4.1	15	.012"
Hydr. Lime	2.0	5.6	2.7	42	.038"
Powdered Fibrous Type	2.0	5.3	3.1	44	.036"

Considerable reduction in expansion occurred with the fillers added (Figure 14). No cracks were visible in these specimens. Although the Kaolin filler with 7.0% asphalt reduced the maximum expansion to 0.012", the amount of asphalt was excessive as far as stability was concerned. The reason for selecting the Kaolin was that previous investigations along this line had demonstrated its beneficial influence on volume changes.

GRADE OF ASPHALT vs EXPANSION

Another factor which has an influence on expansion is the grade of asphalt as indicated by a recent series of tests on AC bars with uniformly graded aggregate but varying the grade of asphalt. The three types of asphalt of primary interest are:

A) 200 - 300 penetration
B) 85 - 100 "
C) 60 - 70 "

The purpose of this phase of the expansion-contraction study is a determination of the effect, if any, of heavier grades of asphalt on expansion.

We know, from past experience, that heavier grades of asphalt will usually prevent or retard stripping, and in most cases, reduce swelling in water-susceptible aggregates. It was reasoned, however, that the results from the expansion-contraction test would give us a direct comparison as to the amount the heavier grades of asphalt would reduce expansion.

The following cases are presented to show the influence the grade of asphalt has on expansion.

A set of AC bars was fabricated from a rather high

(0.5%) absorptive aggregate. The grades and the recommended asphalt content used were:

a) 200 - 300 5.3% = 3.9 (Micron) Av. Film Thick

b) 60 - 70 5.3% = 3.9 " " " "

(Note: We did not have sufficient material to make a test bar using 85-100)

The maximum expansion for these test bars after six weathering cycles were:

a) 200 - 300 = 0.086"

b) 60 - 70 = 0.063"

During the 3rd Cycle the test bar with 200-300 asphalt had cracked, while cracks did not appear on the test bar with 60-70 asphalt until the 6th cycle.

In another example (Test #65-1401) we used 200-300 and 85-100 penetration asphalt. The aggregate showed 0.5% absorption. By using 5.0% asphalt the following maximum expansion was obtained after 6 test cycles:

200 - 300 penetration = 0.089" expansion

85 - 100 " = 0.052" "

Figure 15 shows the plotted data.

The limited test data obtained so far does show that heavier grades of asphalt will decrease expansion in AC mixes. However, more data will be required before we can come to any positive conclusion.

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 16, representing a moderately high absorptive aggregate, shows that the maximum expansion has been decreased from 0.052" to 0.014" by increasing the average asphalt film thickness by one micron. The same increase in film thickness of a nonabsorptive or slightly absorptive aggregate will only reduce the expansion slightly, as i.e. from 0.014" to 0.012" after 3 exposure cycles.

CONCLUSIONS

From the test data presented the following conclusions can be drawn:

1. There exists a relationship between the per cent absorption of the aggregate and the expansion and contraction of the mix. Generally, the higher the absorption, the greater the expansion.

2. Maximum expansion usually occurs during the wet testing cycle. Maximum contraction occurs during the dry cycle.

3. AC test bars generally continue to expand during the test cycles and usually do not return to their

original length.

4. Tests to date show expansion can be reduced by removing expansive clays from the aggregate mix.

5. Expansion can be reduced by certain mineral fillers while others may encourage expansion.

6. Tests show that use of the harder grades of asphalt and increases in asphalt content have a tendency to decrease expansion of the mix.

7. Studies made to date show good correlation between expansion bar behavior and actual pavement performance.

From the data obtained so far, it would appear that we should re-evaluate some of our test methods for determining what is, and what isn't, a "good" aggregate for use in constructing asphalt concrete pavements. A considerable number of aggregates, some presently used in the construction of our AC mixes, meet all standard routine specification tests but still fail to give satisfactory performance on the road. We are now in the process of setting maximum absorption values for this type of aggregate. It is certain that some of the currently used pits will be either eliminated or that the aggregate will require some sort of treatment in future construction.

Many engineers have a tendency to blame the asphalt and the amount used when an AC pavement shows distress. There is no question that this is the cause in many instances. Considerable progress is being made today to insure the production of more durable asphalts. However, it might behoove us to take a closer look at the aggregates being used in the construction of AC pavements. It may well be that with X-ray and DTA analysis and development of test procedures similar to those described in this report, we will be able to eliminate the poorer aggregates and thus obtain more durable asphalt pavements.

REFERENCES

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2. Test Method No. Calif. 303, Method of Test for Centrifuge Kerosene Equivalent.
3. F. N. Hveem, E. Zube, and J. Skog - Proposed New Tests and Specifications for Paving Grade Asphalts, Proceedings of the Association of Asphalt Paving Technologists, San Francisco, February 1963.

A portion of this work was done in cooperation with the U. S. Department of Commerce, Bureau of Public Roads (HPR1(2) D-3-13).

This paper was not completed in time to allow a complete review and, therefore, the findings and conclusions expressed here are not necessarily those of the Bureau of Public Roads.

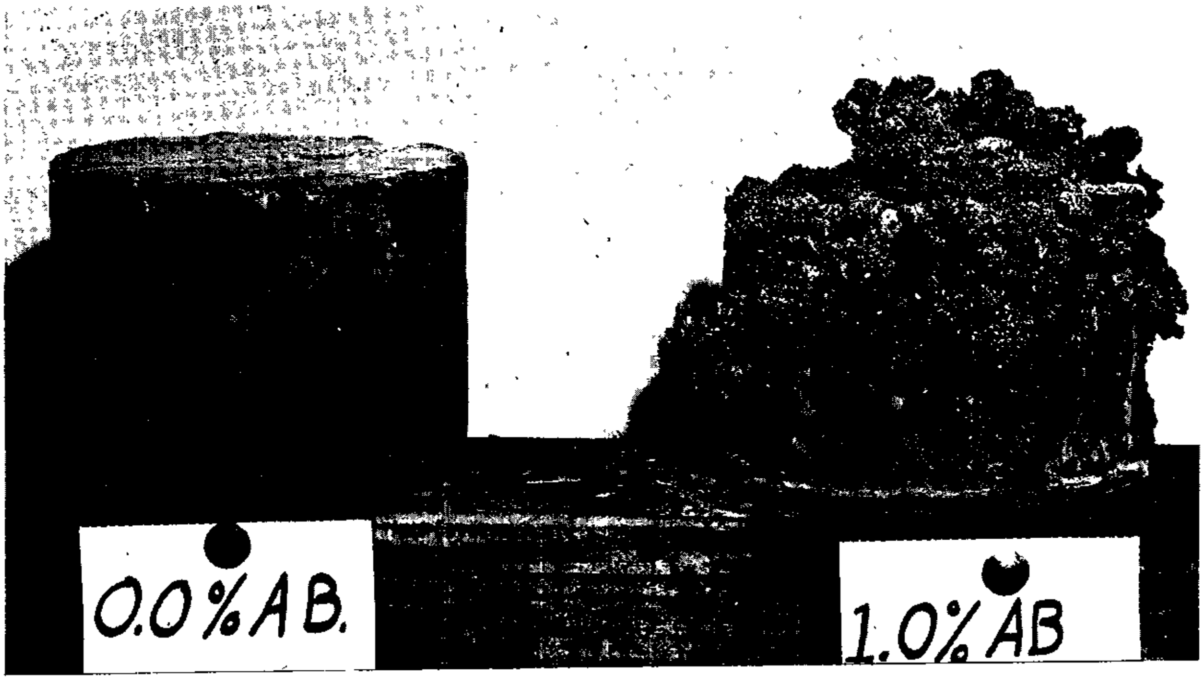


Fig. 1 - Epoxy coated specimen after 1 year exposure on roof.
Left - Nonabsorptive aggregate.
Right - Absorptive aggregate.

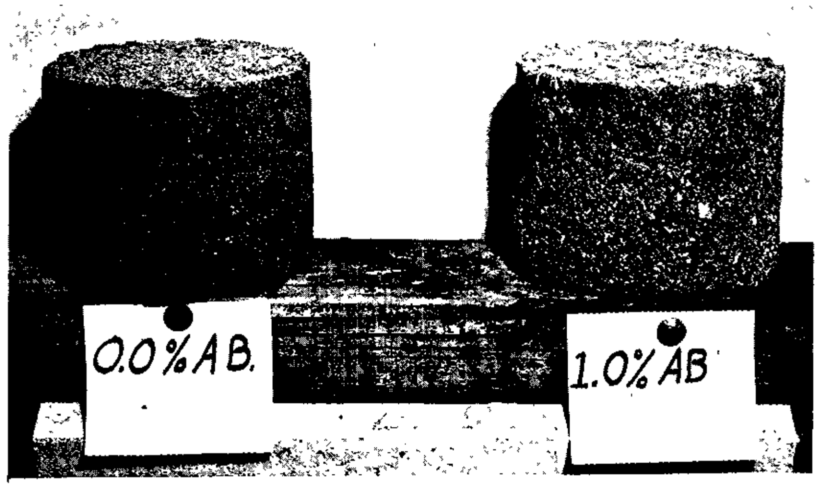


Fig. 2 - Noncapsulated specimen exposed on roof after 6 months.
Left - Nonabsorptive aggregate.
Right - Absorptive aggregate.

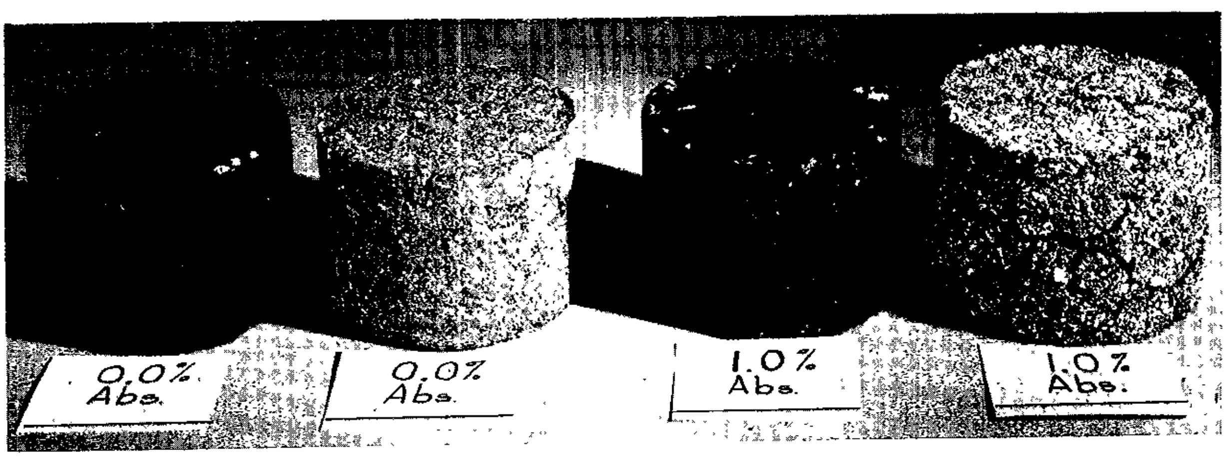


Fig. 3 - Absorptive and nonabsorptive AC briquettes.
Dark colored specimen stored in cabinet for 6 years.
Light colored specimen exposed on roof for 6 years.

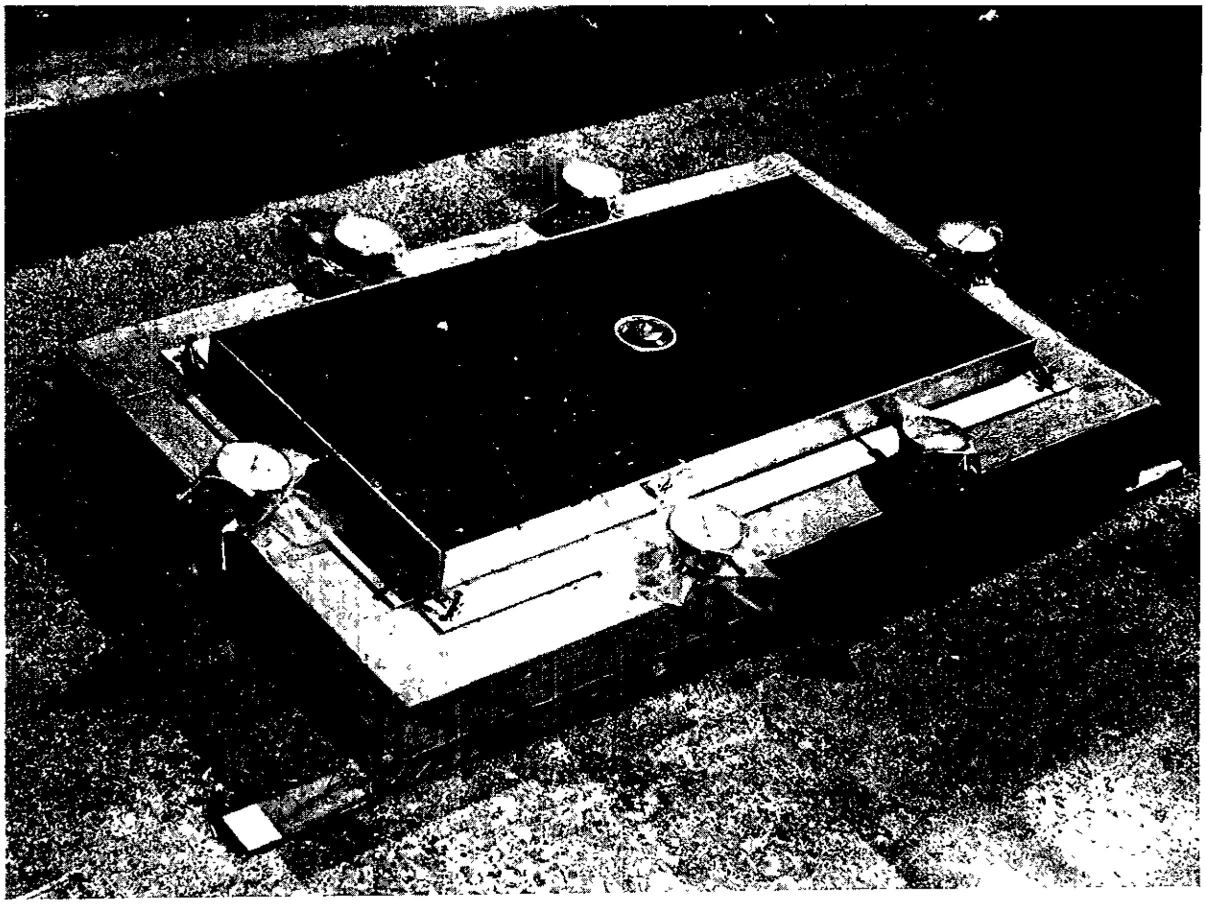
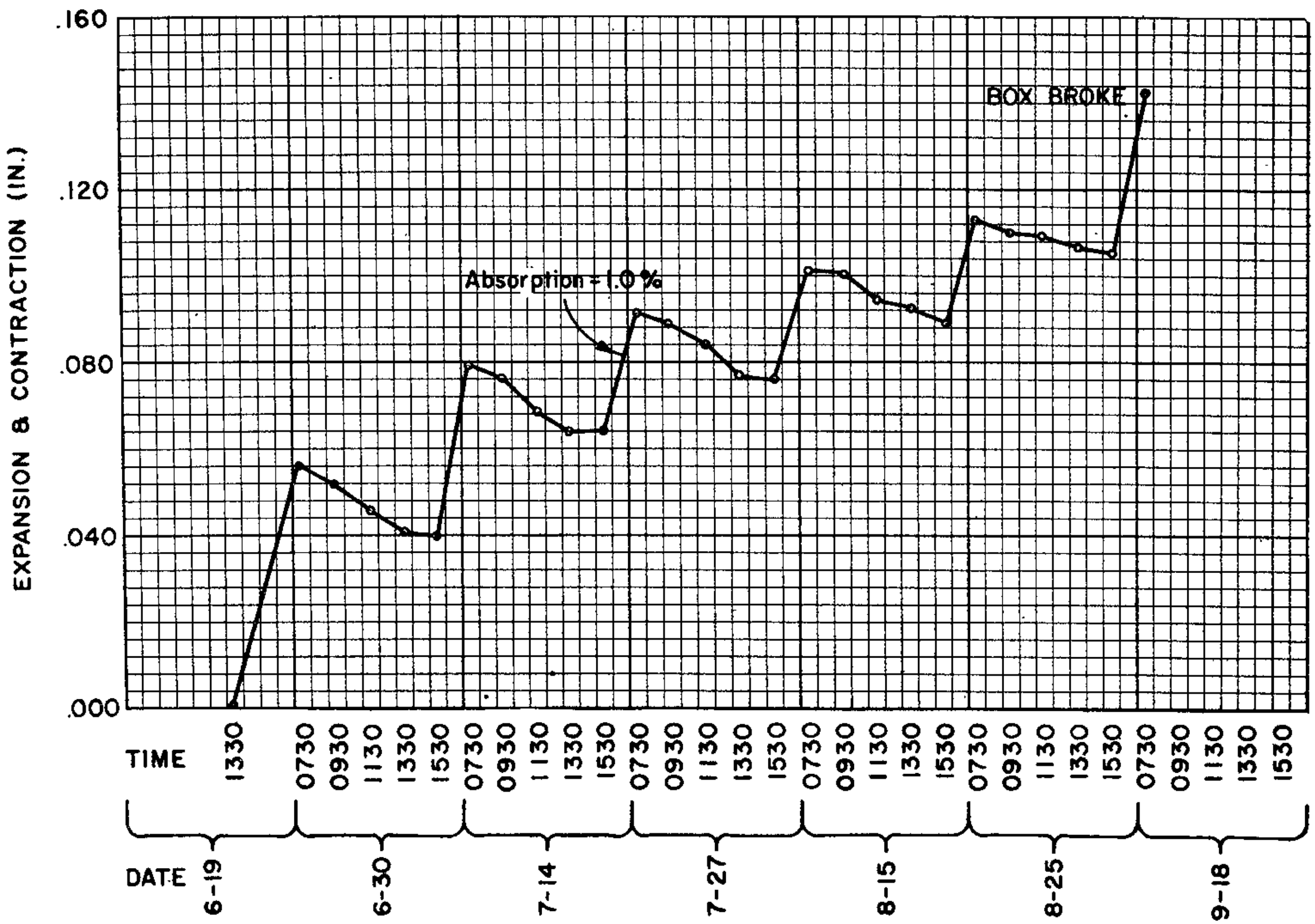
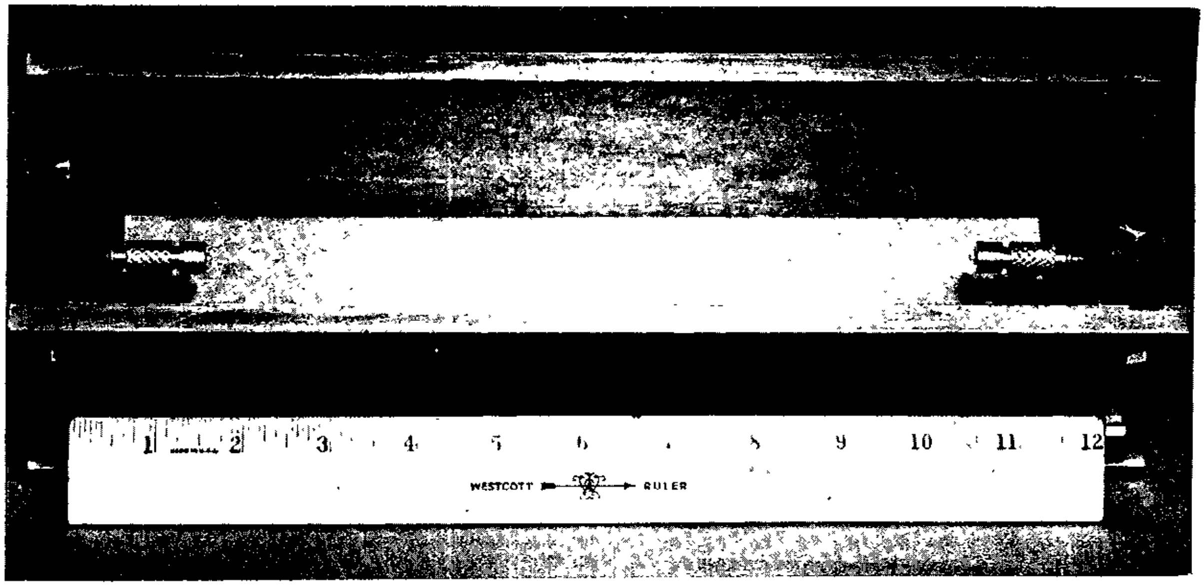


Fig. 4 - Slab specimen 1' x 2' x 3". Note springs holding aluminum sides surrounding surface course.

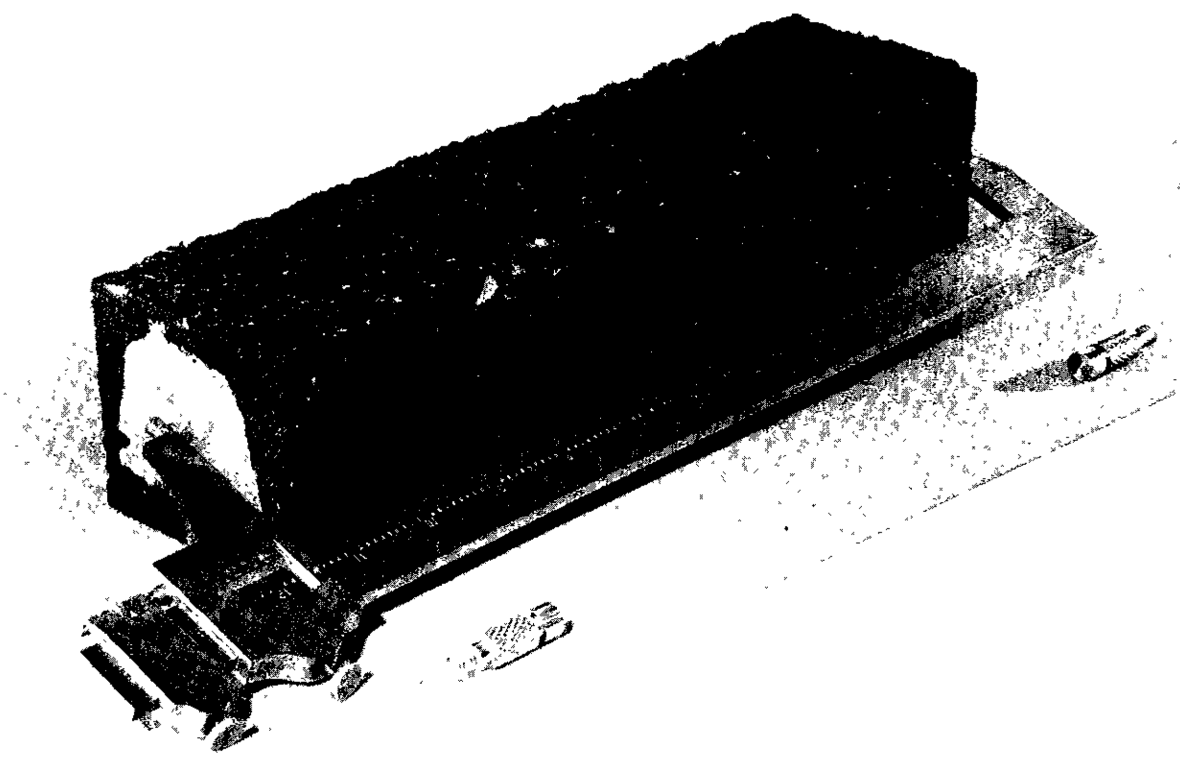


TEST NO. 57-1236

FIGURE 5

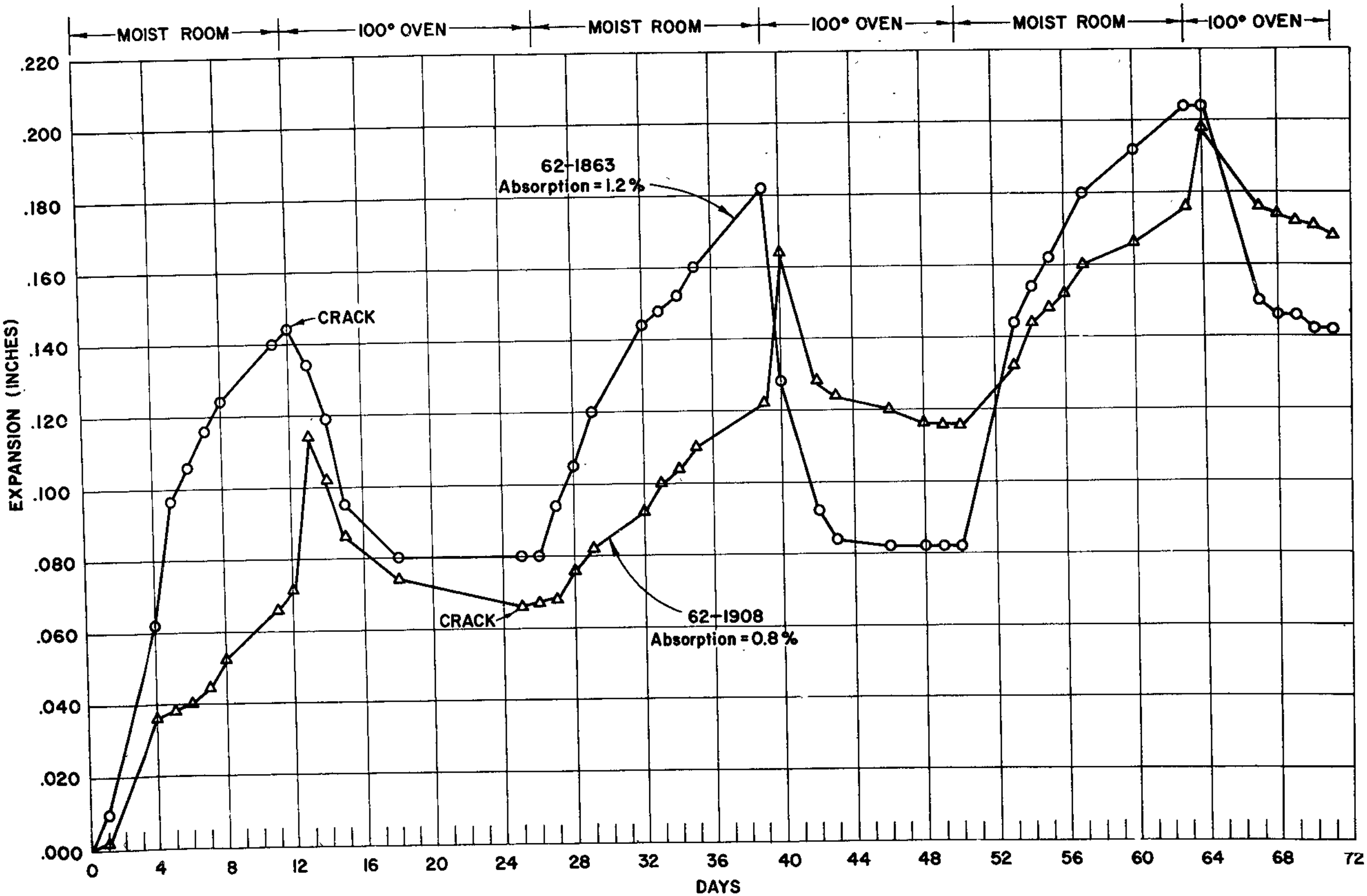


Steel molds 3" x 3" x 11.25" used for fabricating bars.
Note steel pins in end of plates for measuring AC bars.



Bar after being stripped, ready for measurement.

Fig. 6



TEST NO'S. 62-1863 & 62-1908

FIGURE 7

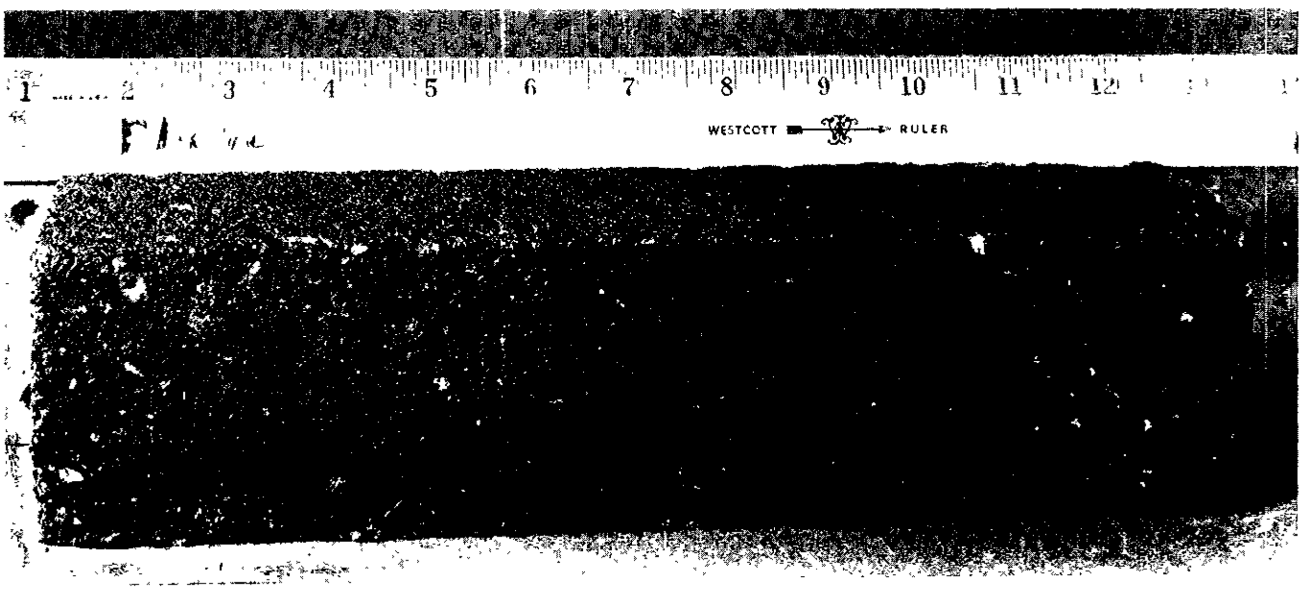


Fig. 8 - Test bar 62-1908.
Transverse cracks appeared after the first cycle.

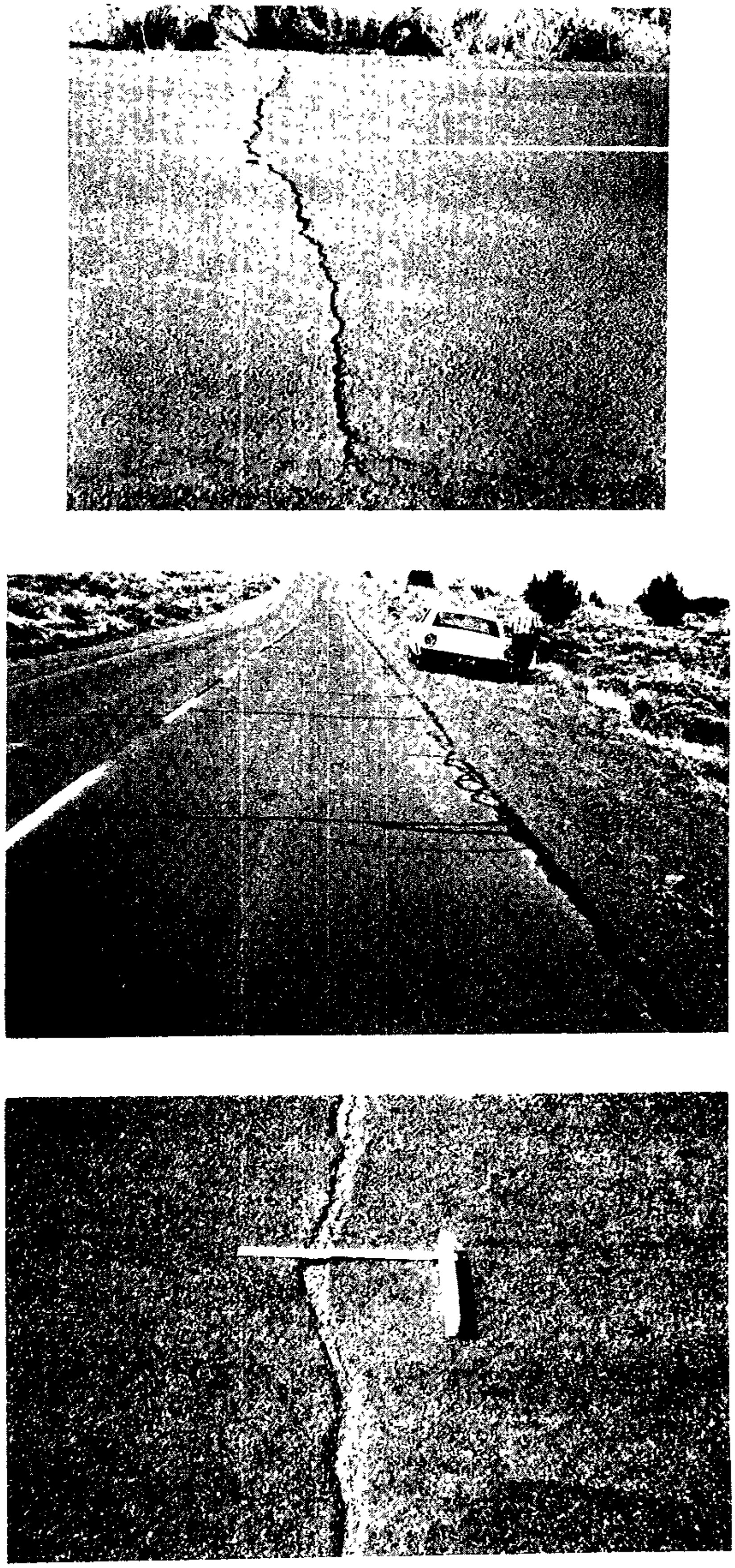
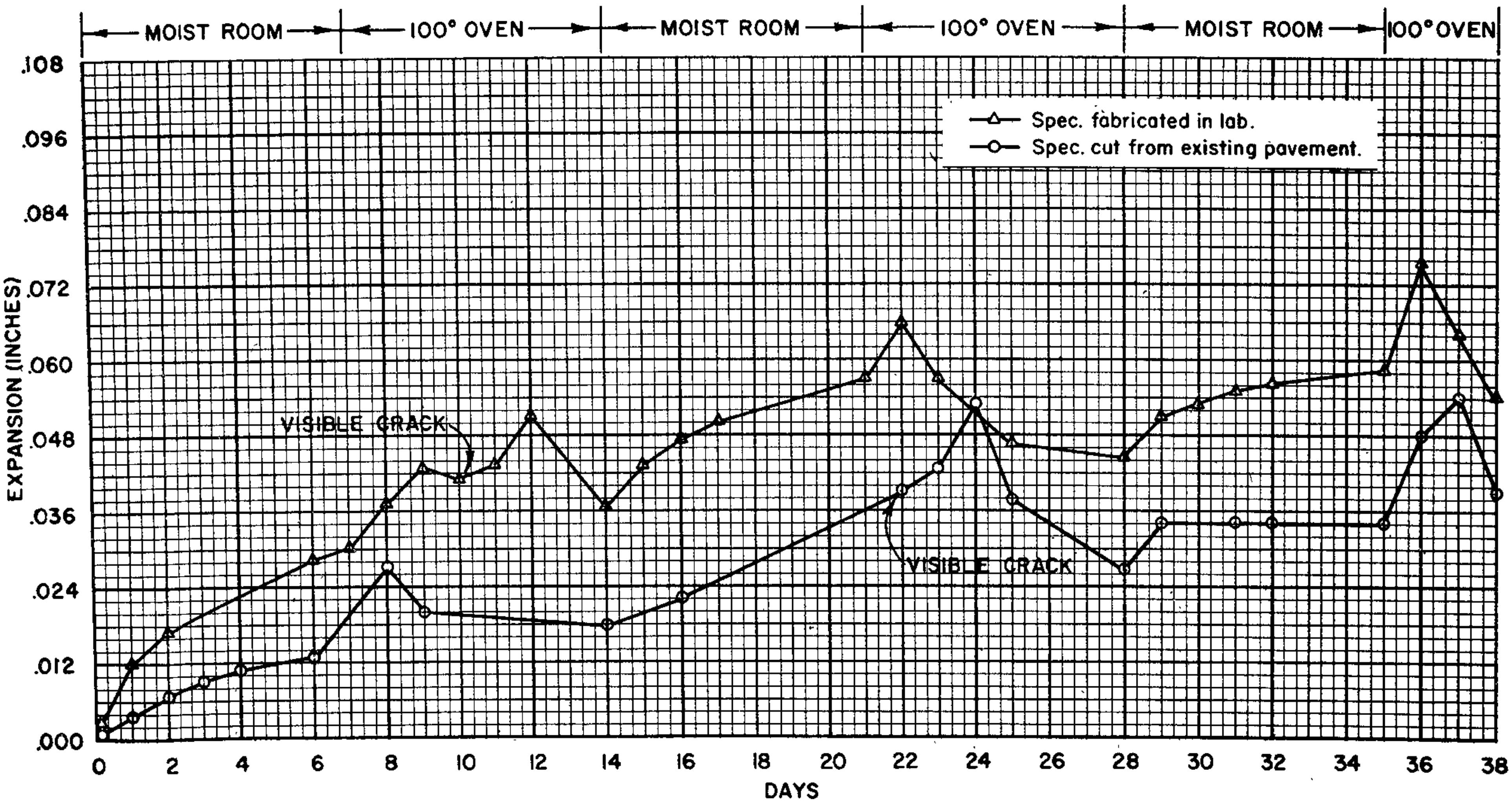


Fig. 9



TEST NO. 62-5748

FIGURE 10

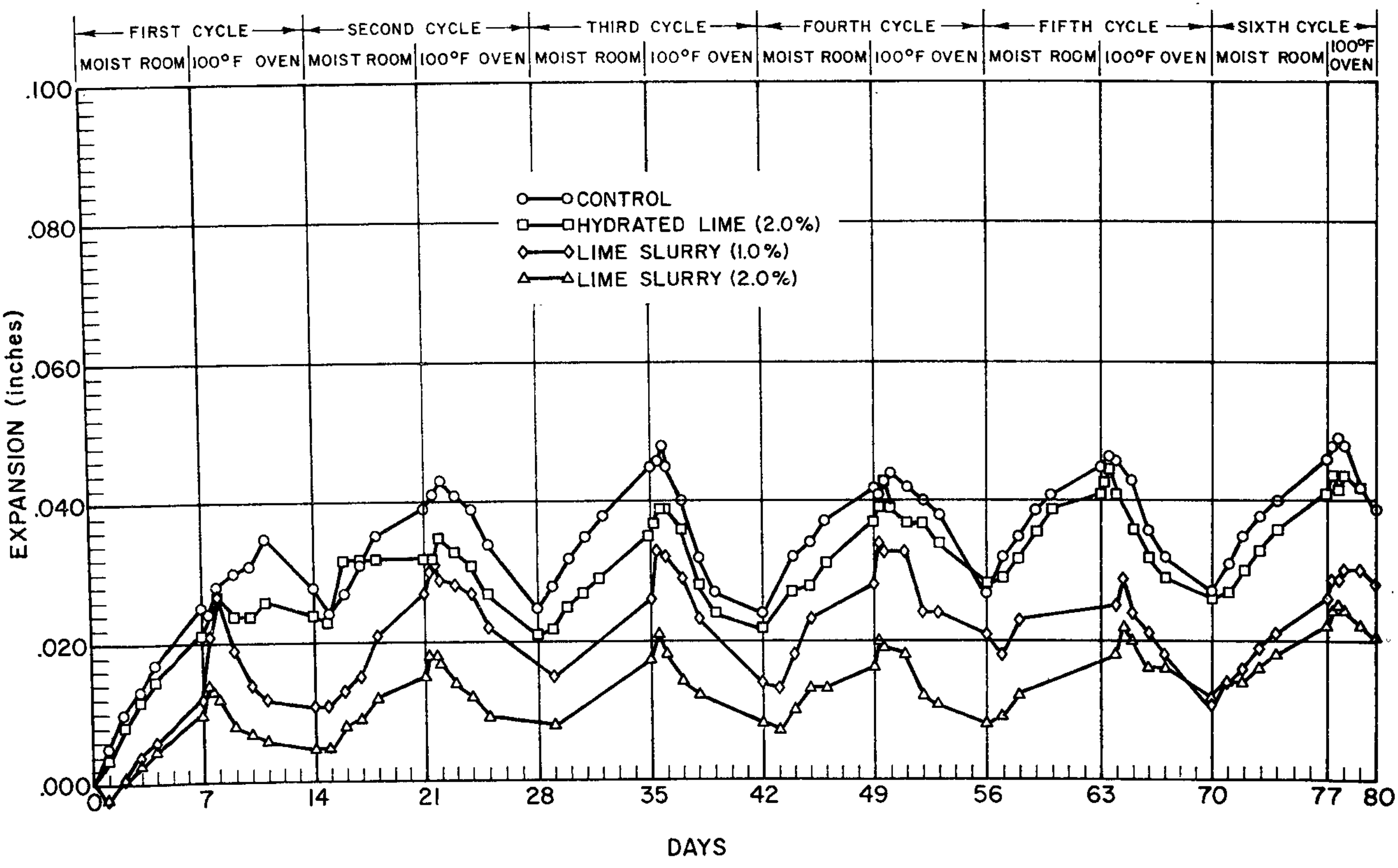

FIRST CYCLE
SECOND CYCLE
THIRD CYCLE
FOURTH CYCLE
FIFTH CYCLE
SIXTH CYCLE
MOIST ROOM
100°F OVEN
CONTROL
HYDRATED LIME (2.0%)
LIME SLURRY (1.0%)
LIME SLURRY (2.0%)
EXPANSION (inches)
.100
.080
.060
.040
.020
.000
0
7
14
21
28
35
42
49
56
63
70
77
80
DAYS

FIGURE 11

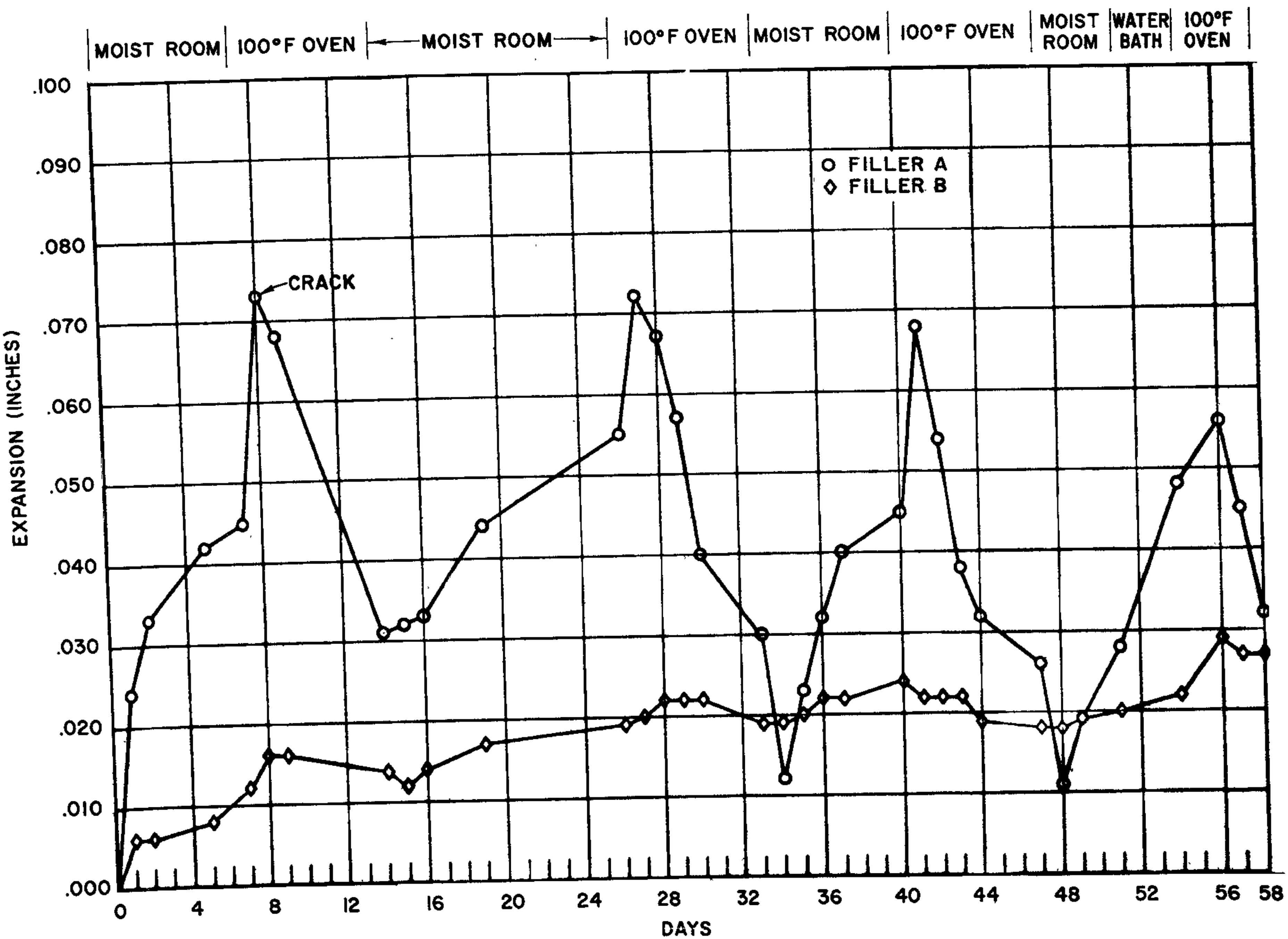
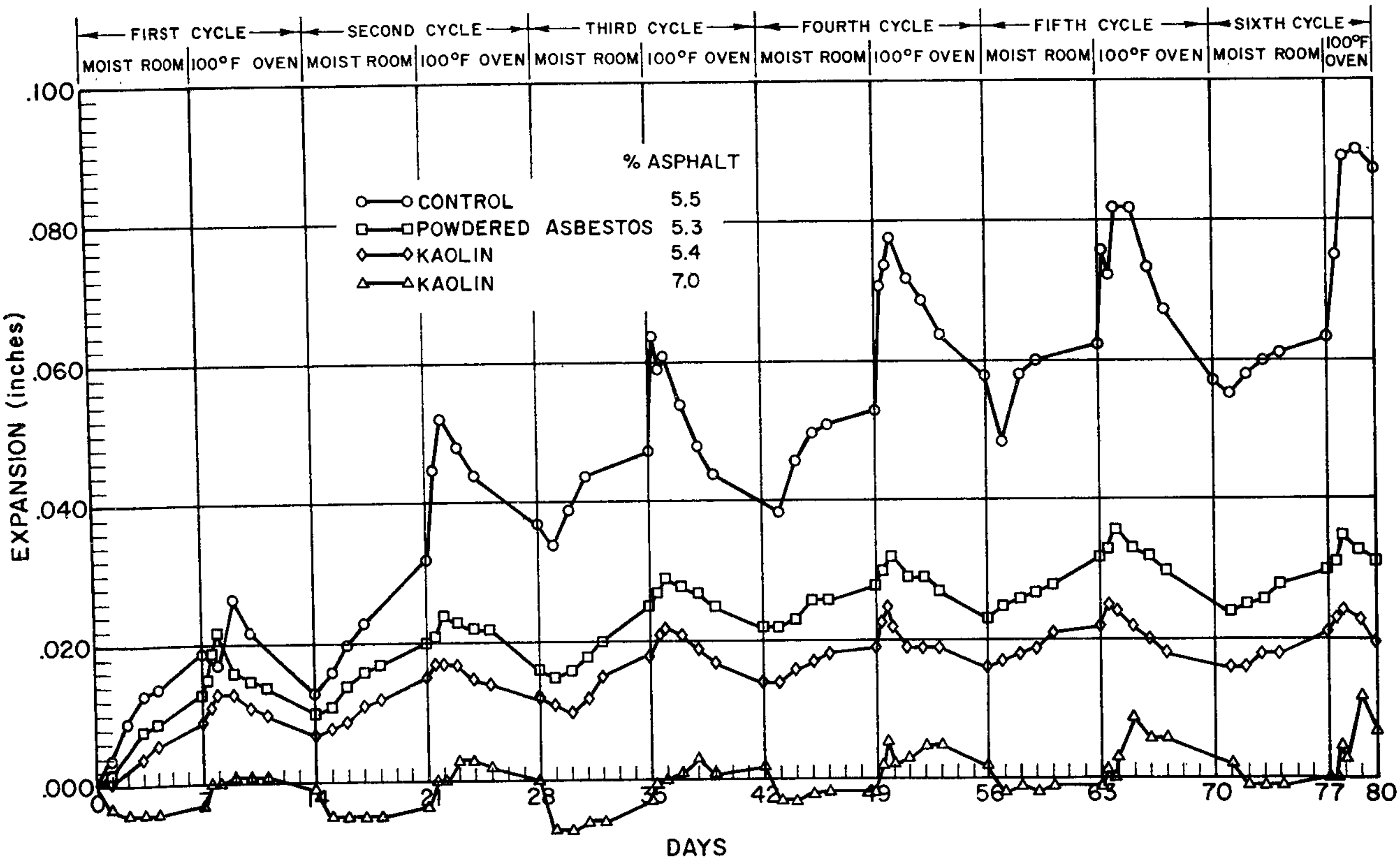

MOIST ROOM
100°F OVEN
MOIST ROOM
100°F OVEN
MOIST ROOM
100°F OVEN
MOIST ROOM
WATER BATH
100°F OVEN
CRACK
O FILLER A
◇ FILLER B
EXPANSION (INCHES)
.100
.090
.080
.070
.060
.050
.040
.030
.020
.010
.000
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
58
DAYS

FIGURE 12

Fig. 13



FIRST CYCLE
SECOND CYCLE
THIRD CYCLE
FOURTH CYCLE
FIFTH CYCLE
SIXTH CYCLE
MOIST ROOM
100°F OVEN
% ASPHALT
CONTROL 5.5
POWDERED ASBESTOS 5.3
KAOLIN 5.4
KAOLIN 7.0
EXPANSION (inches)
.100
.080
.060
.040
.020
.000
0
7
14
21
28
35
42
49
56
63
70
77
80
DAYS

FIGURE 14

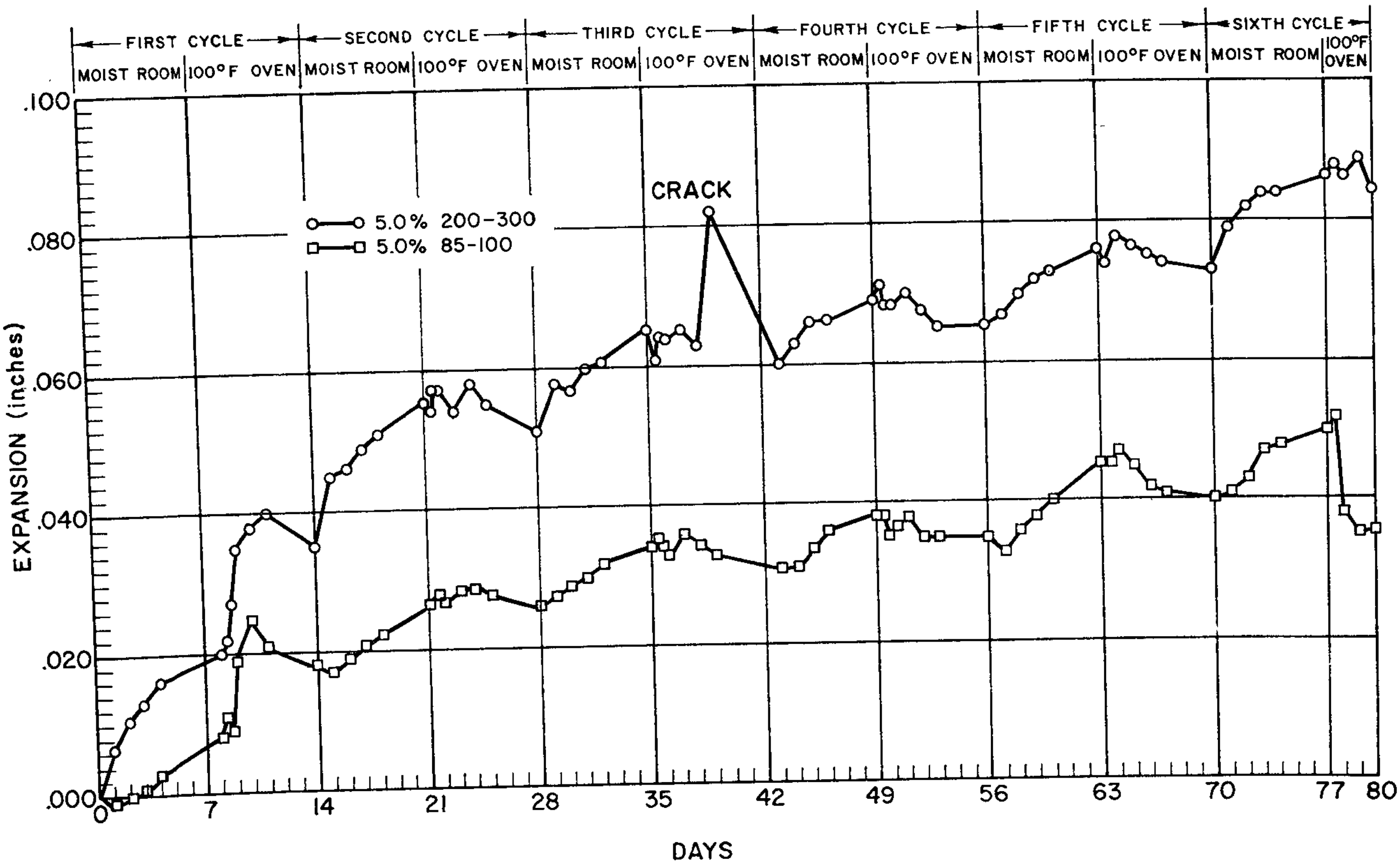

FIRST CYCLE
MOIST ROOM
100°F OVEN
SECOND CYCLE
MOIST ROOM
100°F OVEN
THIRD CYCLE
MOIST ROOM
100°F OVEN
FOURTH CYCLE
MOIST ROOM
100°F OVEN
FIFTH CYCLE
MOIST ROOM
100°F OVEN
SIXTH CYCLE
MOIST ROOM
100°F OVEN
.100
.080
.060
.040
.020
.000
EXPANSION (inches)
5.0% 200-300
5.0% 85-100
CRACK
0
7
14
21
28
35
42
49
56
63
70
77
80
DAYS

FIGURE 15

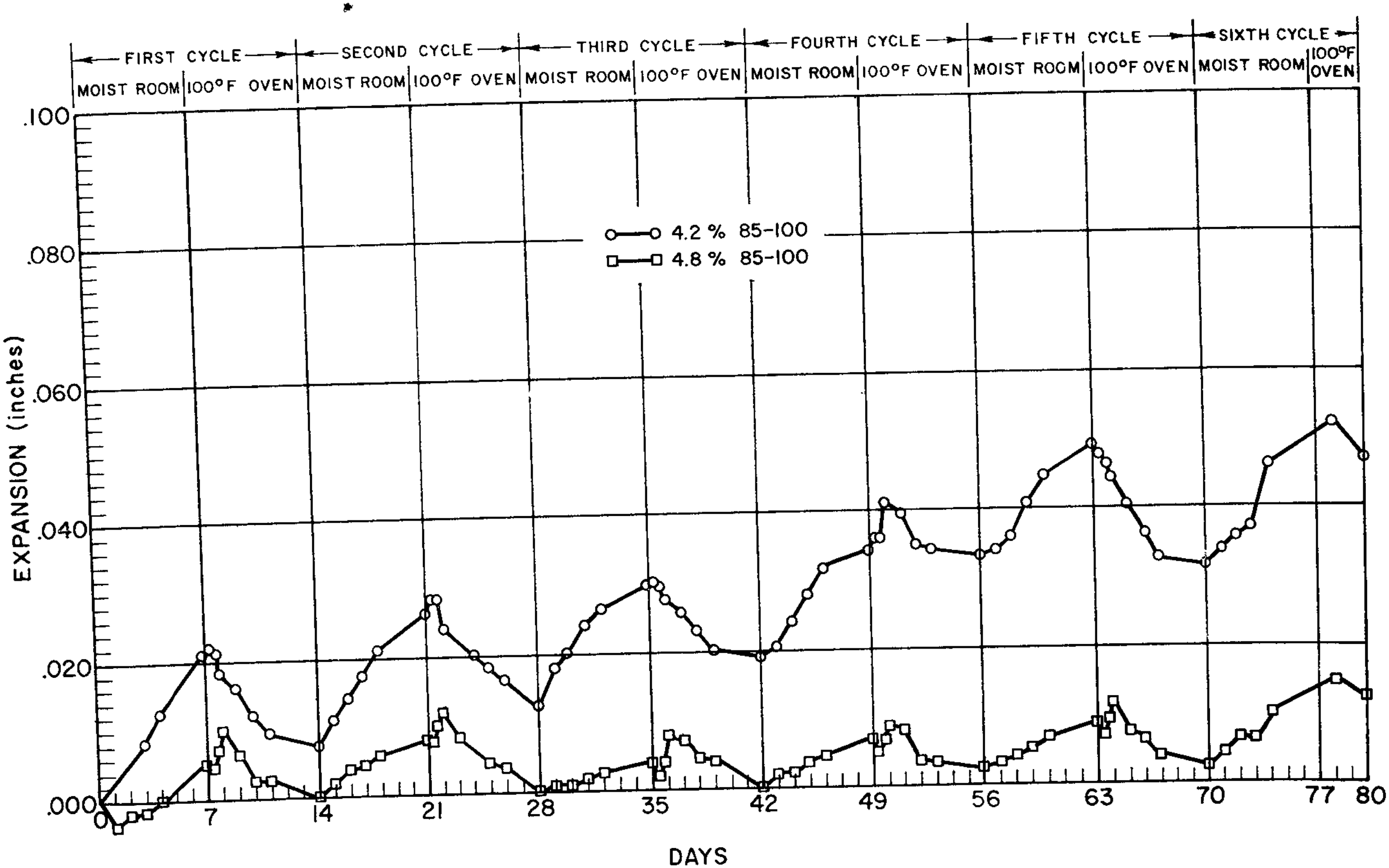

FIRST CYCLE
SECOND CYCLE
THIRD CYCLE
FOURTH CYCLE
FIFTH CYCLE
SIXTH CYCLE
MOIST ROOM
100°F OVEN
4.2 % 85-100
4.8 % 85-100
EXPANSION (inches)
.100
.080
.060
.040
.020
.000
DAYS
0
7
14
21
28
35
42
49
56
63
70
77
80

FIGURE 16