A LABORATORY EVALUATION OF MODIFIED ASPHALT

FINAL REPORT

BY

DONALD E. CAREY
BITUMINOUS RESEARCH ENGINEER

AND

HAROLD R. PAUL
RESEARCH ENGINEER-IN-TRAINING

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METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
	Length	
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
	Area	
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
	Volume (Capacity)	
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
	Mass	
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbm)	kilogram (kg)	907.2
	Mass per Volume	
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
	Temperature	
deg Celsius (C)	kelvin (K)	$t_K=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_K=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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ABSTRACT

Quality aggregate availability in southern Louisiana has reached an alarmingly low level, while naturally occurring materials (sands) have been ignored due to their poor structural properties. Recent research reported by Chem-Crete Corporation indicates that structural properties of sand mixes incorporating Chem-Crete binder compare favorably with dense-graded asphaltic concrete. This binder, processed according to a new refinery technique, is purported to improve asphalt properties such as strength, durability, temperature susceptibility and water resistance. These attributes and other properties of sand/Chem-Crete mixes are examined in this report. Generally, upon curing, sand mixes utilizing Chem-Crete binder demonstrated properties equal to or superior to Louisiana's dense-graded Type 1 asphaltic concrete (1200-pound stability).

IMPLEMENTATION STATEMENT

The recommendations of this report call for the construction of an experimental field trial utilizing a sand/Chem-Crete mix. The information gathered in this study such as binder content optimization, viscosity-temperature susceptibility, and fundamental properties will form the basis for both project and mix design for this trial.

INTRODUCTION

Since the mid 1970s Louisiana research has directed attention in the area of material conservation. This direction has stemmed from a steadily decreasing quality aggregate supply and increased transportation costs. Successful research has been achieved with recycling in which virgin aggregate demands can be reduced and with sulphur mixes in which sand could be substituted for quality aggregate. However, recycling is not always applicable and sulphur, at this time, is not economically feasible.

In light of Louisiana's research, the state was approached by Chem-Crete Corporation. The company had developed a new refinery technique which was purported to improve asphalt properties such as strength, durability, temperature susceptibility, and water resistance. The increased structural capacity of Chem-Crete mixes due to the improved strength characteristics would allow for the use of non-quality aggregates such as sand. According to the literature, successful projects utilizing desert sands were constructed in the Middle East and Nigeria. It was decided that the Chem-Crete binder deserved consideration.

In November 1979 this research study was initiated to examine, in the laboratory, the physical characteristics of Chem-Crete binder and sand/Chem-Crete mixes. An agreement was signed prohibiting the chemical analysis of the Chem-Crete sample as international patents for the process were pending. The binder was to be characterized by penetration (77°F), viscosity (140, 275, 350°F), and ductility (77°F). Optimization of binder content for three different gradations (coarse to fine) was attempted using the Marshall method. Additional mix properties such as retained strength, resistance to water, fundamental properties and strength-temperature susceptibility were examined. This report presents the findings of the laboratory testing program.

SCOPE

The aim of this evaluation was to determine in the laboratory the properties of a modified asphalt--Chem-Crete--with respect to binder characterization and its compatibility with Louisiana sands. This study was conducted in five phases:

Phase I - Binder properties testing;

Phase II - Sand/Chem-Crete mix optimization, Marshall method;

Phase III - Other sand/Chem-Crete mix properties;

Phase IV - Fundamental properties testing (Indirect Tensile Test); and,

Phase V - Quick-cure Chem-Crete testing.

METHODOLOGY

Phase I - Binder Properties

The technology involved in the production of Chem-Crete binder pertains to the refinery process. In order to facilitate this study, a concentrate of a Chem-Crete processed California crude was forwarded, to be blended with Louisiana asphalt cements. One part Chem-Crete concentrate was blended with nine parts of Louisiana AC-30 asphalt cement.

The first phase of this study consisted of binder properties testing including penetration (77°F), absolute viscosity (140°F), kinematic viscosity (275, 350°F), and ductility (77°F) for two different sources of asphalt cement (Exxon and Lion) and blends of these asphalts with the Chem-Crete concentrate. Tests were conducted on both the original samples and after subjection to the Thin Film Oven. Results are presented in Table 1.*

Phase II - Sand/Chem-Crete Mix Optimization

The Marshall method of mix design was used to optimize the binder content for the sand/Chem-Crete mixes. Sand/asphalt mixes were also optimized for use as a control. Three aggregate gradations were examined (90/10, 80/20, 70/30 coarse sand to fine ratios) at each of three binder contents (ranging from 8 to 11 percent). It was felt that such a matrix could fully explore the potential of the sand/Chem-Crete mixes. Only the coarsest and finest gradations were used for the sand/asphalt control samples. Mix gradations are shown in Table 2. Exxon AC-30 was used as the asphalt cement source for this phase.

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*All tables may be found in the Appendix (page 27).

The Chem-Crete briquettes were compacted at a mix temperature of 300°F using a 75 blow design. A cure period of 15 days in a 140°F oven was recommended by the producer to assure that the maximum effects of the Chem-Crete binder would be realized. Marshall properties are presented in Table 3. As can be observed in this table, it was necessary to construct additional briquettes to optimize the Marshall stabilities.

Sand/asphalt samples were compacted at a mix temperature of 325°F using a 75 blow design. These briquettes were tested the same day they were fabricated. Marshall properties can be found in Table 4.

Once familiarization with optimum stabilities of cured Chem-Crete mixes was obtained, the feasibility of a test for field use was examined whereby same-day stabilities could be determined for mix control requirements. Briquettes were tested according to standard procedure (no cure time) and after curing for 16 hours in both 140°F and 275°F ovens. A 90/10 aggregate ratio was chosen for the mix design. The previously completed optimization work had determined an asphalt cement content of 6.5 percent for this gradation. Additionally, sand/asphalt briquettes were constructed and subjected to a 275°F oven for 16 hours. These specimens were used as a control to examine the possibility of the contribution of oxidation to the strength of the Chem-Crete briquettes. Table 5 presents the Marshall properties associated with this testing.

Phase III - Other Mix Properties

This phase of the test program was used to observe mix properties other than those obtained by the Marshall optimization. Retained strength, stripping tests, and strength-temperature relationships were examined. In addition, a Lion/Chem-Crete binder was incorporated in an optimized mix design from Phase II to verify the applicability of Chem-Crete with another asphalt cement. The effect of film thickness was also examined in this phase.

A 90/10 coarse sand to fine sand ratio with varying asphalt contents of 5, 6 and 7 percent was used to observe the retained strength characteristics of the Chem-Crete mix. All briquettes were cured for 15 days at 140°F. Testing for Marshall stabilities was conducted after 24 and 48 hours of immersion in a 140°F water bath. These stabilities along with percent strength retained are presented in Table 6. Also included in this table are the stabilities found during the optimization testing.

Loose Chem-Crete mix was examined for stripping susceptibility in a ten-minute boil test. In this test loose mix is placed in a jar, covered with water and heated to boiling. After boiling for ten minutes, the material is removed and dried on paper towels. A visual examination is then made. The Chem-Crete mix consisted of the 90/10 gradation material blended with 5, 6 and 7 percent binder. Prior to testing, some samples were cured for 15 days at 140°F while others were tested in a non-cured state. A sand/asphalt mix was used as a control, meeting the identical gradation, binder content and curing conditions. Table 7 shows the visual ratings of the boil test.

In order to verify the applicability of this Chem-Crete concentrate with other Louisiana asphalt cements, a testing matrix utilizing Lion AC-30 was designed. Based on the optimization of mix design in Phase II, a mix design of 90/10 coarse sand/fine sand aggregate ratio with 6 percent binder was selected. Included in this matrix is the varying of cure time under both ambient and 140°F oven temperatures to develop strength-cure time relationships. Viscosities were examined to determine the extent of oxidation due to the uncommon exposure to heat imposed by the long cure times. Table 8 summarizes the results.

Strength in terms of Marshall stability was examined with regard to temperature susceptibility. Binders for this testing included Lion/Chem-Crete, Exxon/Chem-Crete, Lion, and Exxon. Briquettes were cured for 30 days at ambient temperature and were tested at ambient, 100°F, and 140°F. The composition of the briquettes was 90/10 sand aggregate ratio and 6 percent binder. Additionally, uncured briquettes using Lion as the binder were investigated as a control. Stabilities are presented in Table 9.

As claimed by the Chem-Crete producers and substantiated by the Marshall design optimization, Chem-Crete performs best when used in a thin film. In order to examine the strength relationship to both time and film thickness, a 9 percent binder level, 90/10 aggregate ratio mix was tested after cure times of 15, 30, and 60 days in a 140°F oven. Both Exxon/Chem-Crete and Exxon were used as binders. Water susceptibility was also examined in a 24-hour Marshall immersion test. Table 10 contains the data obtained from this testing.

Phase IV - Fundamental Properties

In this phase, the Indirect Tensile Test was utilized to determine fundamental properties of Chem-Crete mixes such as modulus of elasticity, tensile stress at failure, and both tensile and compressive strains. Briquettes were constructed of an 80/20 sand ratio with a 6 percent Exxon/Chem-Crete binder level. These briquettes were cured at 140°F for periods of 1, 7, and 14 days. Conventional dense-graded asphaltic concrete (Type 1 wearing course, 1200-pound stability) briquettes were tested and used for comparative purposes. Results are presented in Table 11.

Phase V - Quick-Cure Chem-Crete

Although most of the testing associated with Chem-Crete appeared positive, some concern was expressed with regard to the cure time necessary to obtain full strength. As the majority of roadway work might be in the overlay mode, the Chem-Crete mixes would be required to withstand traffic shortly after construction. In response to this concern, the Chem-Crete producers forwarded a faster curing Chem-Crete concentrate.

A testing program was devised to determine the ability of this quick-cure Chem-Crete to develop strength within an acceptable time frame. One part concentrate was blended with 9 parts Lion asphalt cement. Mix designs comprised of 5 and 6 percent binder with an 80/20 sand aggregate ratio were cured for 1, 6 and 24 hours under ambient and 140°F oven conditions. Twenty-four-hour Marshall immersion tests were run along with original viscosities and with viscosities after the thin film oven. Some briquettes containing 5 percent binder were also cured for 72 hours. The results of this phase are contained in Table 12.

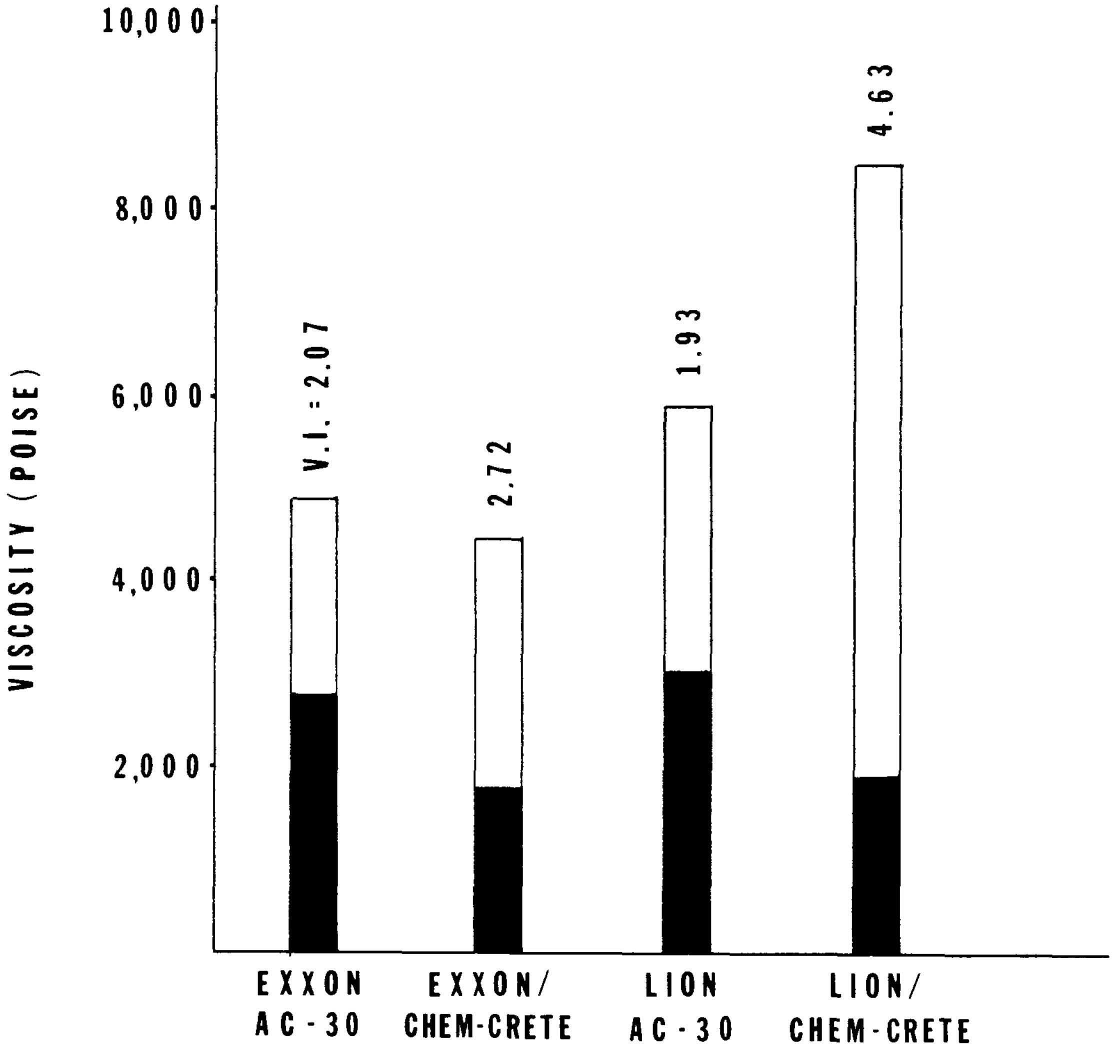
DISCUSSION OF RESULTS

Phase I - Binder Properties

Both asphalts showed an increase in penetration and a corresponding decrease in viscosity when blended with the Chem-Crete concentrate. Such changes may be related to excess distillate (contained in the concentrate for shipment) which was not burned off during the heating and blending process. Ductilities for Exxon/Chem-Crete and Lion/Chem-Crete were greater than 100.

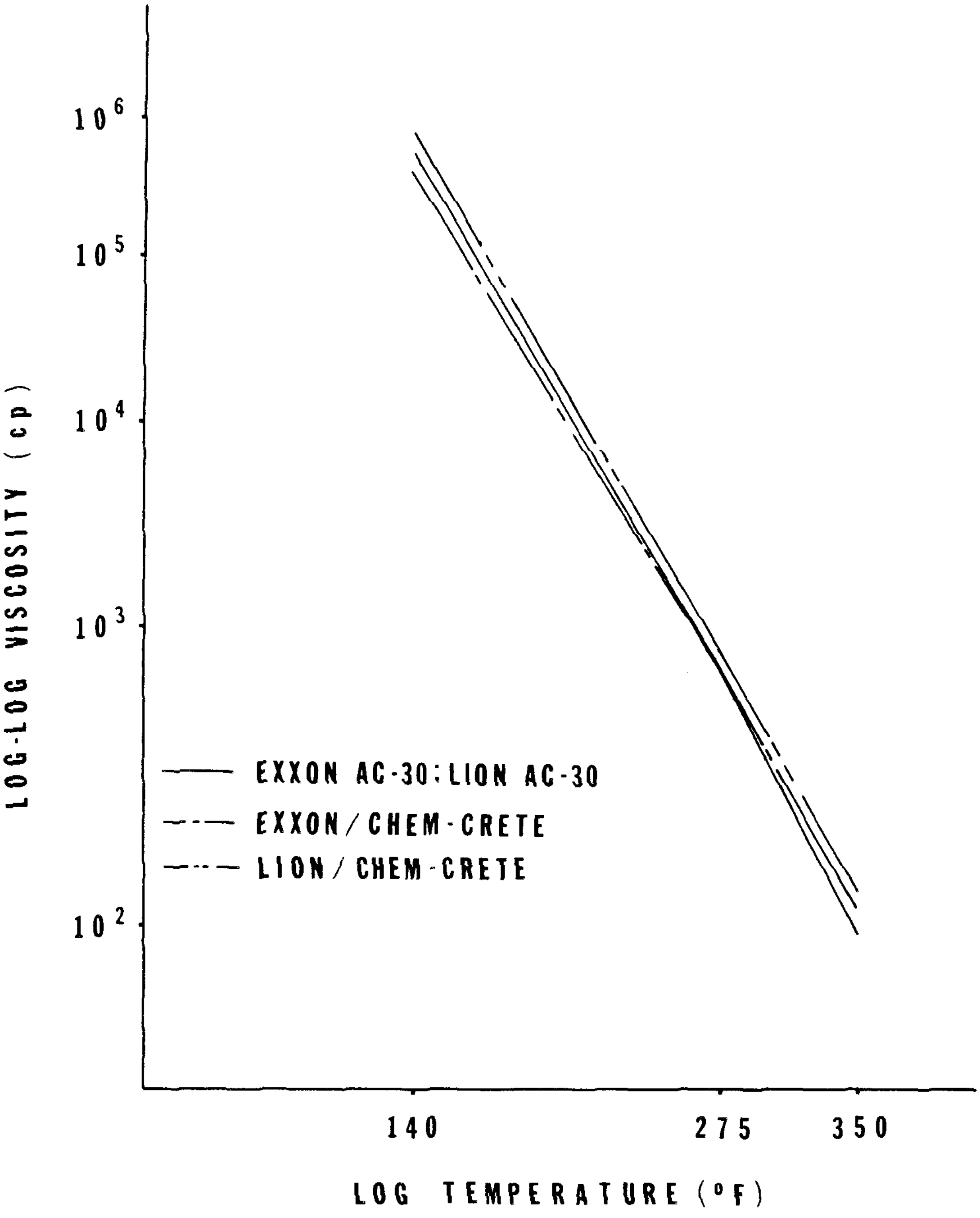
The viscosity indices (V.I.) for the original Exxon and Lion asphalts were 2.07 and 1.93, whereas the Chem-Crete blends were 2.72 and 4.63, respectively (computed from data contained in Table 1). Figure 1 shows these values graphically. The solid bar represents the viscosity prior to the Thin Film Oven test, and the clear portion of the bar shows the viscosity after exposure to the Thin Film Oven. Louisiana has established 4.0 as the maximum allowable viscosity index for asphalts used in the state. Under this specification the Lion/Chem-Crete blend would be considered susceptible to oxidation. Chem-Crete's producers responded that higher than normal indices are typical of the Chem-Crete material and are not indicative of oxidation. Due to the conditional agreement with Chem-Crete Corporation, the binder could not be analyzed further. It was decided to examine other mix properties such as Marshall flow and tensile strain in order to draw conclusions regarding oxidation.

Data from the viscosity testing was used to examine the temperature susceptibility of the Chem-Crete binders. Figure 2 depicts the relationships found. Table 13 (page 41) presents the slopes of the curves for each binder between 140°F to 275°F and 275°F to 350°F. The slopes of the Lion and Exxon AC-30 are identical and are represented by the same curve. Blended Lion/Chem-Crete parallels the curve for the original asphalts, indicating a similar temperature susceptibility. The Exxon/Chem-Crete blend, however, shows that the



Viscosity Indices

FIGURE 1



TFO Viscosity-Temperature Susceptibility

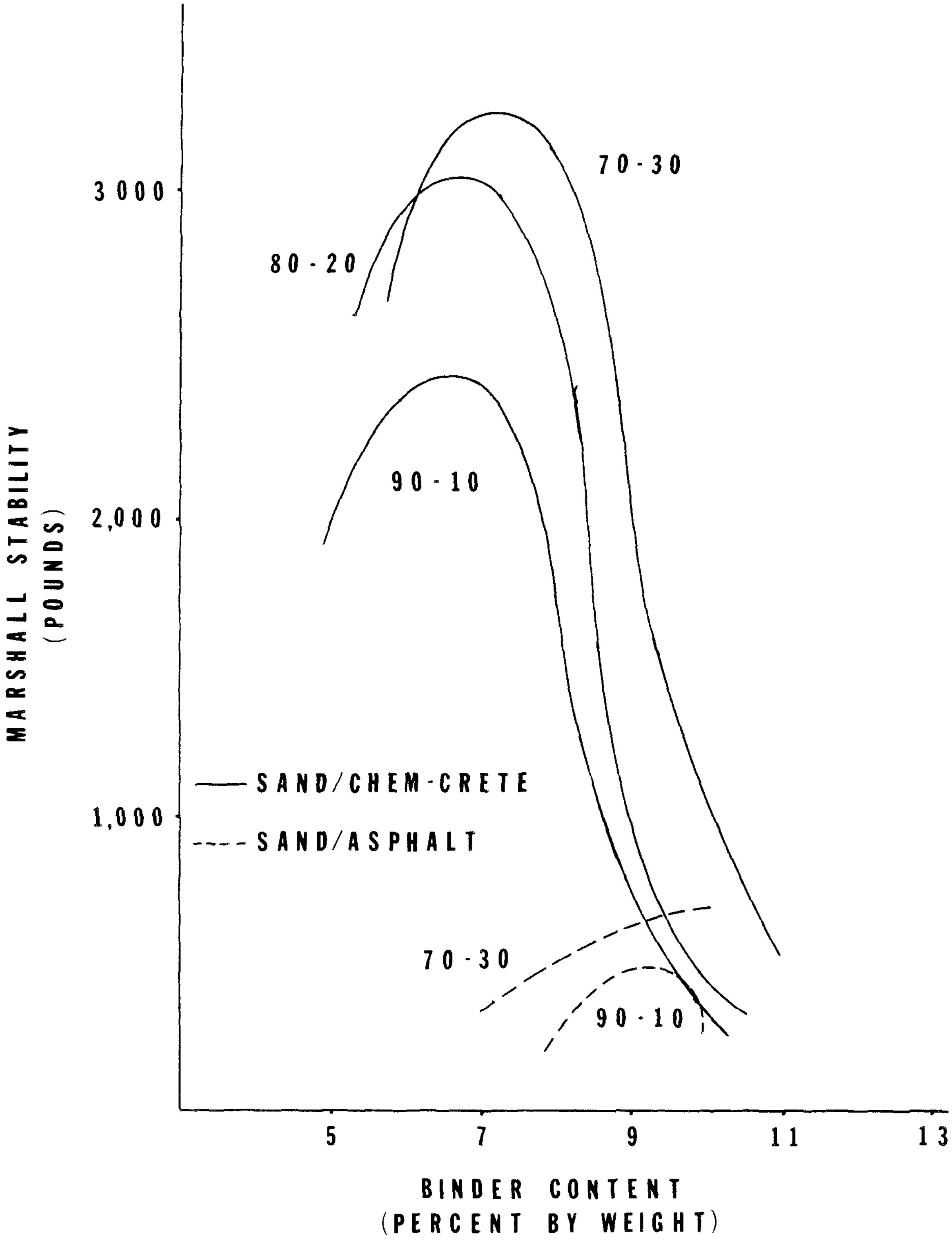
FIGURE 2

viscosity of this binder is less susceptible to temperature in both the 140°F - 275°F and the 275°F - 350°F ranges.

Phase II - Sand/Chem-Crete Mix Optimization

Figure 3 graphically presents the Marshall stability data associated with Tables 3 and 4 (pages 31 and 32) for the sand/Chem-Crete and sand/asphalt mixes. Marshall optimization with respect to binder content occurs between 6.5 and 7 percent for the Chem-Crete mixes. The sand/asphalt mixes would require a binder content of 9 percent or greater. In addition to lowered binder content, a sixfold increase in strength was observed with the Chem-Crete mixes. The stabilities found with the sand/Chem-Crete mixes (2400-3300 lbs.) were greater than the strengths normally associated with Louisiana's conventional Type 1 (low volume-1200-lb. stability) dense-graded mix. It should be noted that the flow values of these mixes were not indicative of the presence of oxidation. This finding relieved suspicion stemming from the higher than normal viscosity index found in the Phase I testing program.

Acceptance penalties under the state's Quality Assurance Specifications presently preclude the aging of Marshall briquettes during construction for testing purposes. In an attempt to determine a method of testing which could be correlated to fully cured briquettes, the data of Table 5 (page 33) was obtained. Sixteen hours of curing would allow for next-day stability determination, and 275°F was set as the maximum temperature allowable without the possibility of oxidation. The table shows that approximately 60 percent of the full cure stability (1539/2500) can be achieved at 275°F/16 hours for the Chem-Crete mix. The sand/asphalt mix, however, also attained a rather high stability under these curing conditions. It was felt that this increase was due to some oxidation and that the 275°F oven temperature was probably affecting the Chem-Crete briquette stabilities.



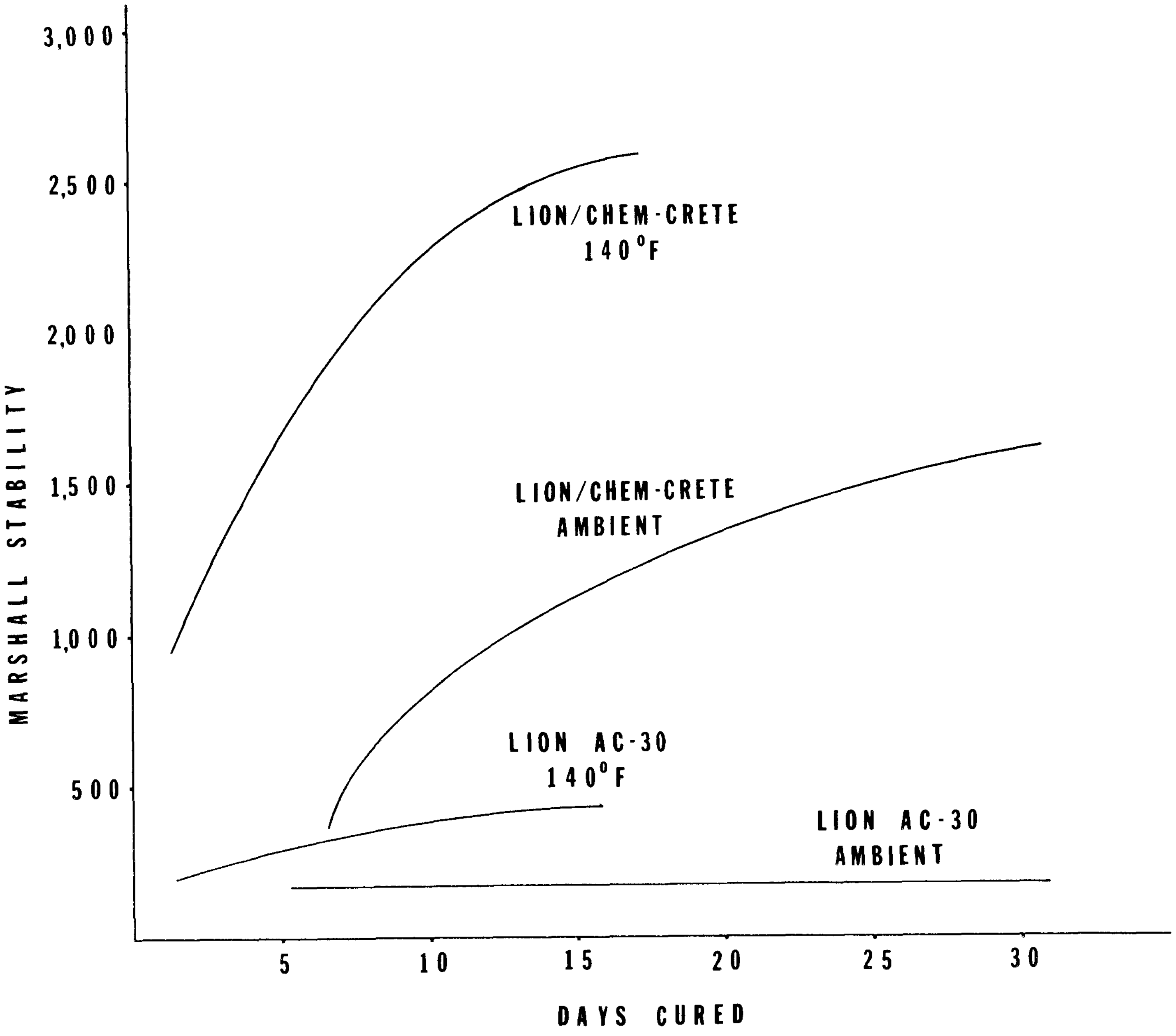
Marshall Optimization

FIGURE 3

Phase III - Other Mix Properties

Marshall immersions and a 10-minute boil test were used to examine the effect of water on the Chem-Crete mixes. Retained strengths after a 24-hour immersion for the Chem-Crete mixes composed of the most open gradation were very consistent as shown in Table 6 (page 34). The range of 58 to 62 percent, however, is lower than the 75 percent desired for conventional dense-graded mix. Yet, these values appeared adequate when considering the high air voids in the sand/Chem-Crete mix. Because of unfamiliarity with sand mixes, it was decided to increase the severity of the immersion. Briquettes were exposed to the bath for 48 hours and then broken. The percent strength retained was again registered as 58, indicating that the 24-hour test was sufficient and that a rather stable plateau had been reached with respect to water damage. The percent swell for all samples was 1.0 percent or less. Cured Chem-Crete mix performed better than fresh Chem-Crete, cured Exxon AC-30 and fresh Exxon AC-30 at all binder levels examined in the 10-minute boil test (Table 7, page 35).

Also in this phase, the strength-cure time relationship was examined. Figure 4, which is based on the data found in Table 8 (page 36) presents this relationship for Lion/Chem-Crete mix. This mix produced results similar to the Exxon/Chem-Crete 90-10 mix when cured for 15 days in a 140°F oven. It is interesting to note that while the Lion/Chem-Crete left to cure at ambient temperature had not reached the oven-cured samples after 30 days, it was seen to be superior to the sand/asphalt mix. The binder from each of the 15-day briquettes was recovered and tested for viscosity at 140°F to determine if an extensive amount of the stability increase in the oven-cured samples could be attributed to oxidation. A slight increase in stability was observed in the oven-cured Lion AC-30. There was a corresponding increase in viscosity, but not more than that associated with the Thin Film Oven Test (Table 1, page 29), while surprisingly large viscosities were obtained with the Chem-



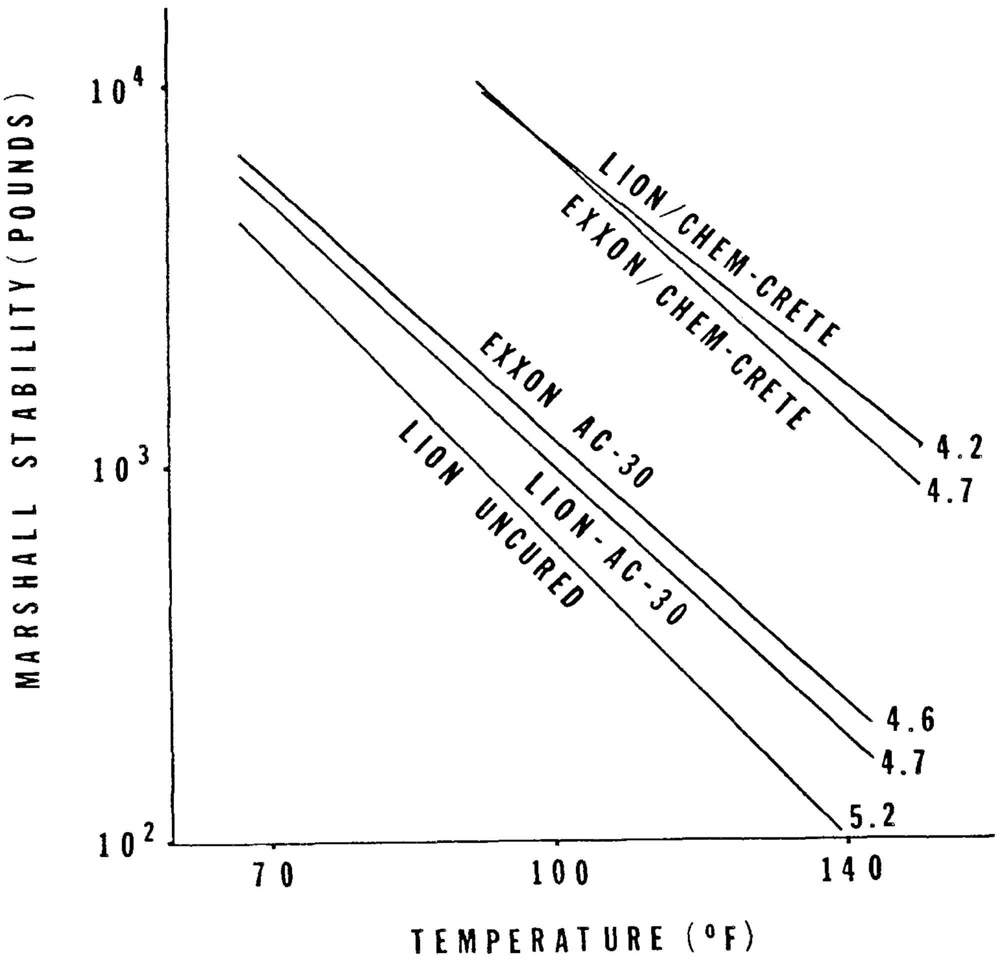
Strength-Cure Time Relationship

FIGURE 4

Crete binder in both the oven-cured and ambient-cured samples. Since the Lion/Chem-Crete binder had a TFO viscosity of approximately 8,000 poises, it is felt that the ambient-cured binder viscosity of 67,250 poises was due to properties associated with the chemical reaction of the Chem-Crete concentrate and the Lion AC-30 and not due to oxidation. This assumption appears justified by the value of the flow, which is not representative of an oxidized binder.

Marshall briquettes were tested at various temperatures to determine the strength-temperature relationship of the Chem-Crete mixes. Figure 5 shows the data collected (Table 9, page 37) in the form of susceptibility curves. It is observed that the cured sand/asphalt mixes, Lion and Exxon, possess less temperature-susceptible Marshall properties than the uncured Lion mix. Further, it is shown that the slope of Lion/Chem-Crete mix is less (flatter curve) than that of the sand/Lion mix, thus demonstrating a decrease in temperature susceptibility. The Exxon/Chem-Crete mix, however, did not display this same trend as the slope of its curve remained approximately the same.

As the last segment of this phase, the effect on strength of film thickness and cure time was examined. It was found that film thickness plays an important part in the development of Chem-Crete mix strength. Figure 6 relates this aspect in strength-cure time curves for two binder levels. Data for these curves was taken from Tables 8 and 10. As can be observed in this figure and in Table 10, the 9 percent Exxon Chem-Crete mix does not begin to develop until sometime after 30 days, while the 6 percent Lion/Chem-Crete shows an increase in 2-6 days. Also, the viscosity data shows that the chemical reaction which increased the 6 percent binder level to 200,000+ poises in 15 days does not occur in the 9 percent binder mix until after 30 days. Approximately 75 percent of Marshall stability was retained for the 60-day sample. The 30-day sample retained 170 percent. It is possible that the strength development begins to occur close to the 30-day period and that the heat from the water bath increased the strength of the 30-day specimen.



Strength-Temperature Susceptibility

FIGURE 5

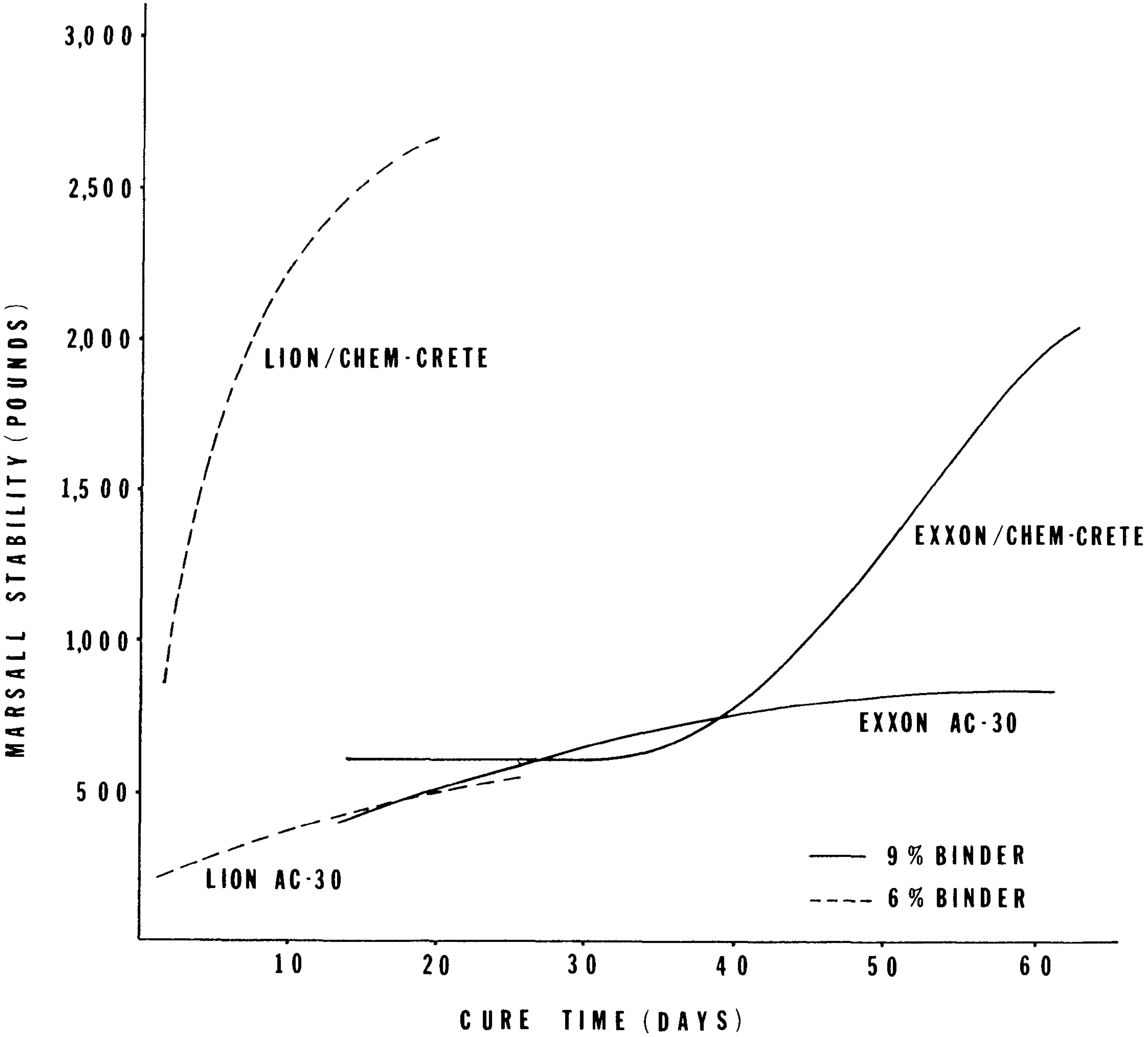


FIGURE 6

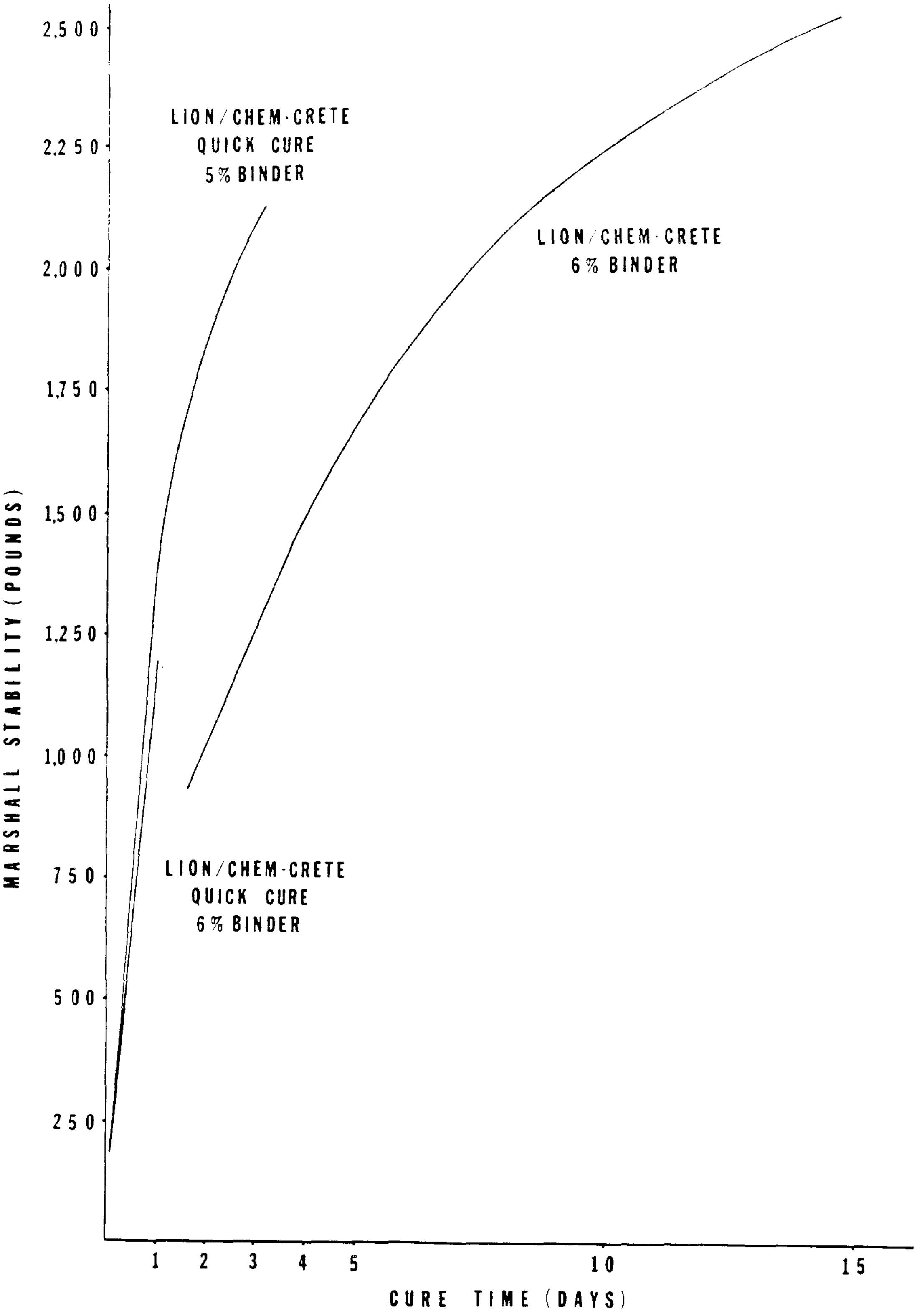
Strength-Cure Time Relationship for Thick Binder Mixes

Phase IV - Fundamental Properties

Generally, the data presented in Table 11 (page 39) demonstrates that the Chem-Crete mix is much stiffer than the conventional dense-graded mix, confirming the trend observed in the Marshall optimization. An average modulus value of 4.196 x 10^5 psi of the fully cured Chem-Crete briquettes shows a fourfold increase over the Type 1 mix and the tensile stress (psi) at failure shows a threefold increase (153.37 versus 57.50). The tensile strains (total and elastic) were analyzed for variation according to ASTM E 178. Using the independent standard variation method, it was found that no significant variation existed between the Chem-Crete tensile strains and those of the conventional briquettes at the 5 percent level. The compressive strains, both total and elastic for the 1-day Chem-Crete samples and the total for the 14-day Chem-Crete samples, failed to pass this variation test at the 5 percent level. However, the significance of this variation in the compressive strain mode was not considered important when considering the high tensile stresses associated with the Chem-Crete mix and its probable location in a pavement system.

Phase V - Quick-Cure Chem-Crete

A viscosity index of 4.6 (standard viscosity = 1,455; TFO viscosity = 6,633) was found for the quick-cure Chem-Crete binder. This figure is identical to that determined for the regular Lion/Chem-Crete composite binder (Table 1). The Marshall stabilities for briquettes constructed with this binder, as found in Table 12, show a definite increase in strength after 24 hours in the 140°F oven. A further increase was found in the 72-hour samples. Figure 7 shows the nature of the quicker cure Chem-Crete mixes as opposed to the mix composed of the initial Chem-Crete concentrate. The development of the ambient-cured briquettes displayed the same slower trend as was seen with the regular Chem-Crete binder. A retained strength of approximately 30 percent was observed when the 24-hour oven-cured samples were subjected to a 24-hour immersion test. It was felt that the severity of this test on the partially cured briquettes was responsible for the poorer results obtained.



Stability-Cure Time Relationship for Quick-Cure Chem-Crete

FIGURE 7

It is believed that the stabilities obtained with the quick-cure Chem-Crete binder reflect only the strength of the aggregate structure after 6 hours regardless of method of cure. Certainly, increases were observed after 24 hours. It has been the experience of the writers that sand mixes have been able to support construction traffic. Also, the Chem-Crete literature reports no pavement damage due to construction traffic was experienced in their Middle East project. Given that curing is initiated within 24 hours, it is felt that a field trial consisting of a sand mix utilizing a Chem-Crete binder should be considered.

CONCLUSIONS

The following conclusions are drawn from the data generated in this study and, as such, are confined to the sources and grade of the asphalt cements examined:

1. In general, upon curing, sand/Chem-Crete mixes demonstrate Marshall stability and flow values equal to or superior to Louisiana's dense-graded Type 1 asphaltic concrete (1200-pound stability).

2. Fundamental properties such as modulus of elasticity, tensile stress and tensile strain show the sand/Chem-Crete mixes to be able to withstand the same failure strains as conventional dense-graded mixes, yet at significantly higher failure stresses.

3. A Chem-Crete binder shows less tendency to strip than a conventional asphalt cement.

4. Sand mixes with a Chem-Crete binder retain greater than 1,000 pounds stability following 24- and 48-hour water immersions.

5. Sand/Chem-Crete mixes cure faster at lower binder contents (thinner film thickness), which allows for lower binder requirements than would be normally associated with sand/asphalt mixes. Thicker-filmed mixes will achieve similar properties with increased cure time.

6. A cured Chem-Crete binder will possess a much higher viscosity than a conventional asphalt. In fact, the magnitude of such viscosity is directly related to the high mix strength attained with this binder. To assume that these high viscosities are indicative of oxidation-hardening would not seem appropriate in light of the Marshall flow values and tensile strain values obtained.

7. The quicker-cure Chem-Crete bindered mix demonstrated the ability to gain in strength within 24 hours. It is believed that the strengths attained in this time span would be sufficient to withstand construction traffic.

8. A means of curing sand/Chem-Crete briquettes within 24 hours for plant quality control and acceptance testing could not be found.

RECOMMENDATIONS

Based upon the results determined from this laboratory study and the Department's need to successfully incorporate available non-quality aggregate in its construction program, a field trial demonstrating the capabilities of sand/Chem-Crete (quick-cure) mixes is recommended. Of particular interest would be the ability of this mix to bear traffic until such time as the material has fully cured.

It is further recommended that, when possible, chemical analyses of Chem-Crete should be investigated to examine the "apparent oxidation" conditions found during viscosity testing.

APPENDIX

TABLE 1

BINDER PROPERTIES

Test Properties	Exxon AC-30		Exxon and Chem-Crete*		Lion AC-30		Lion and Chem-Crete*	
	Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.
Penetration @ 77°F	57	40	87	48	52	39	78	36
Viscosity poise, @ 140°F	2,834	5,880	1,666	4,539	3,075	5,936	1,820	8,434
Viscosity SFS, @ 275°F	272	364	208	346	268	348	203	414
Viscosity SFS, @ 350°F	50	58	42	59	48	55	44	66
Ductility @ 77°F			100+				100+	

*9 parts AC-30/1 part Chem-Crete.

TABLE 2

SAND AGGREGATE AND MIX GRADATIONS

% Passing	Coarse	Fine	90% Coarse 10% Fine	80% Coarse 20% Fine	70% Coarse 30% Fine
No. 4	100	100	100	100	100
No. 10	98	100	98	98	99
No. 40	61	100	65	69	73
No. 80	8	97	17	25	35
No. 200	3	66	10	15	22

TABLE 3

MARSHALL PROPERTIES: SAND/CHEM-CRETE MIX*

Gradation	Binder** Content	% Air Voids	% V.F.A.	Stability*** @ 140°F	Flow
90-10	5	14.1	42.0	1,980	9
90-10	6	11.5	51.9	2,406	8
90-10	7	9.1	62.4	2,474	10
90-10	8	6.6	71.9	1,821	9
90-10	9	5.0	79.2	727	7
90-10	10	4.7	81.8	257	10
80-20	5.5	12.4	47.7	2,727	11
80-20	6.5	9.9	57.9	3,059	11
89-20	7.5	7.5	67.9	2,957	10
80-20	8.5	5.5	76.7	2,049	11
80-20	9.5	4.5	81.8	595	12
80-20	10.5	4.1	84.4	319	18
70-30	6	12.5	49.4	2,796	11
70-30	7	10.0	59.2	3,264	11
70-30	8	7.3	69.7	3,125	9
70-30	9	6.0	75.9	2,149	11
70-30	10	4.8	81.4	1,021	10
70-30	11	4.1	84.9	558	13

*75 Blow; mix temperature = 300°F.

**% by weight of mix; 1 part Chem-Crete/9 parts Exxon AC-30

***Tested after 15-day cure @ 140°F.

TABLE 4

MARSHALL PROPERTIES: SAND/ASPHALT MIX*

Gradation	Binder** Content	% Air Voids	% V.F.A.	Stability*** @ 140°F	Flow
90-10	8	7.4	69.5	258	8
90-10	9	5.0	79.3	398	12
90-10	10	4.4	82.7	276	14
70-30	7.5	10.8	58.6	437	8
70-30	8.5	8.4	67.6	571	8
70-30	9.5	6.2	76.2	675	11

*75 Blow; mix temperature = 325°F.

**% by weight of mix.

***Tested same day as made.

TABLE 5

QUICK TEST FOR FIELD STABILITIES

Curing Conditions	Marshall Properties			
	Voids	V.F.A.	Stability	Flow
Standard*	10.8	55.4	138	7
16 hrs.* 140°F	10.7	55.8	226	6
16 hrs.* 275°F	10.8	55.4	1,539	6
16 hrs.** 275°F	10.7	55.8	952	7

*90/10 CS-FS ratio; 6.5% AC-30 (Exxon) + Chem-Crete

**90/10 CS-FS ratio; 6.5% AC-30 (Exxon)

TABLE 6

MARSHALL IMMERSION TEST PROPERTIES

Gradation	Binder[1] Content	Stability[2] @ 140°F	Stability[3] @ 140°F	% Retained	Stability[4] @ 140°F	% Retained
90-10	5	1,980	1,166	58.8	1,157	58.4
90-10	6	2,406	1,413	58.7	1,378	57.3
90-10	7	2,474	1,522	61.5	1,448	58.5

[1] % by weight of mix; 1 part Chem-Crete/9 parts Exxon AC-30.

[2] Cured 15 days @ 140°F; no immersion.

[3] Cured 15 days @ 140°F and then immersed for 24 hours @ 140°F.

[4] Cured 15 days @ 140°F and then immersed for 48 hours @ 140°F.

TABLE 7

TEN-MINUTE BOIL TEST VISUAL RATINGS*

Binder Type	Mix Design 90/10 5% Binder	 90/10 6% Binder	 90/10 7% Binder
Fresh Exxon**	C	C	C
Cured Exxon***	C	C	C
Fresh Exxon + Chem-Crete**	B	B	B
Cured Exxon + Chem-Crete***	A	A	A+

*A+ being the least susceptible to stripping.

**Boil after letting mix cool to ambient for 2 hours.

***Boil after oven cured for 15 days @ 140°F.

TABLE 8

MARSHALL PROPERTIES: LION AC-30 AND LION/CHEM-CRETE MIXES*

	Cure Time				
Binder Cure Conditions	2	6	8-9	15	30
Lion/Chem-Crete 140°F					
Stability (lb.)	1,036	1,842	2,166	2,548	
Flow	9	11	12	10	
Viscosity (poise)			200,000+	200,000+	
Lion/Chem-Crete Ambient					
Stability (lb.)		370	558	1,190	1,627
Flow		8	8	10	10
Viscosity (poise)				67,250	152,213
Lion AC-30 140°F					
Stability (lb.)	236	317	365	466	
Flow	8	8	8	8	
Viscosity (poise)			7,842	7,787	
Lion AC-30 Ambient					
Stability (lb.)		179	193	187	193
Flow		7	7	7	7
Viscosity (poise)				3,636	8,548

*90/10 CS-FS aggregate ratio; 6% binder.

TABLE 9

TEMPERATURE-STRENGTH RELATIONSHIP*

	Test Temperature		
	Ambient	100°F	140°F
Lion & Chem-Crete			
Stability		6,916	1,627
Flow		19	10
Exxon & Chem-Crete			
Stability		6,846	1,344
Flow		19	12
Lion			
Stability	4,960		193
Flow	19		7
Exxon			
Stability	5,786		248
Flow	18		7
Uncured Lion			
Stability	3,708		102
Flow	16		7

*90/10 CS/FS aggregate ratio; 6% binder; 30-day ambient cure with exception of uncured Lion.

TABLE 10

THICK FILM
INCREASED CURE TIME*

	Days Cured		
	15	30	60
Exxon & Chem-Crete			
Stability	621	594	1,936
Flow	8	10	12
Viscosity	V = 7,168	V = 7,083	V = 70,790
Exxon			
Stability	465	642	730
Flow	10	12	10
Viscosity	V = 9,530	V = 10,418	V = 11,260
Exxon & Chem-Crete			
24-hr. Immersion			
Stability		1,011	1,445
Flow		13	14

*Cured 140°F oven; 90/10 CS-FS ratio; 9% binder.

TABLE 11

FUNDAMENTAL PROPERTIES

Sample Description	Modulus of Elasticity ε (10^5 psi)	Tensile Stress σ (psi)	Total Tensile Strain $\varepsilon_{\tau\tau}$ (10^{-6} in.)	Elastic Tensile Strain $\varepsilon_{\tau e}$ (10^{-6} in.)	Total Compressive Strain $\varepsilon_{c\tau}$ (10^{-6} in.)	Elastic Compressive Strain ε_{ce} (10^{-6} in.)
Type 1 HMAC (No Cure)	1.0965	57.50	5,481	3,248	5,944	4,568
Chem-Crete 80/20 Grad. 6% Binder 1-Day-140°F	1.9030	98.43	5,340	2,832	8,170	5,957
Chem-Crete 80/20 Grad. 6% Binder 7-Day-140°F	3.7485	154.45	4,350	2,213	5,291	3,948
Chem-Crete 80/20 Grad. 6% Binder 14-Day-140°F	4.1960	153.37	5,033	2,485	4,218	3,485

TABLE 12

MARSHALL PROPERTIES: QUICK CURE CHEM-CRETE*

	Oven Cure 140°F				Ambient		
	1 Hr.	6 Hr.	24 Hr.	72 Hr.	2 Hr.	6 Hr.	24 hr.
5%							
Stability	172	323	1,298	2,125	194	237	492
Flow	6	6	9	10	6	6	7
6%							
Stability	130	290	1,150		168	241	335
Flow	6	6	8		7	6	6
5%							
24-Hr. Immersion							
Stability			378				
Flow			15				
6%							
24-Hr. Immersion							
Stability			358				
Flow			14				

*80/20 CS-FS ratio; Lion/Chem-Crete binder.

TABLE 13

TEMPERATURE SUSCEPTIBILITY SLOPES

	Exxon AC-30		Exxon and Chem-Crete		Lion AC-30		Lion and Chem-Crete	
Temperature Range	Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.
350°-275°F	-3.50	-3.75	-3.25	-3.50	-3.50	-3.75	-3.25	-3.50
275°-140°F	-3.44	-3.44	-3.44	-3.33	-3.44	-3.44	-3.44	-3.44