ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA/AZ-82/159/3

CHEMICAL AND PHYSICAL PROPERTIES OF ASPHALT- RUBBER MIXTURES — PHASE III

VOLUME 3

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June 1982
Final Report

Prepared for:
U.S. Department of Transportation
Federal Highway Administration
Arizona Division

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Chemical and Physical Properties of Asphalt - Rubber Mixtures - Phase III, Volume III - Effects of Diluent		5. Report Date April, 1982 6. Performing Organization Code 2390J030
7. Author(s) J. C. Rosner and J. G. Chehovits		8. Performing Organization Report No.
9. Performing Organization Name and Address Western Technologies, Inc. 3737 East Broadway Road Phoenix, Arizona 85036		10. Work Unit No. 11. Contract or Grant No. HPR-1-19(159)
12. Sponsoring Agency Name and Address Arizona Department of Transportation 206 South 17th Avenue Phoenix, Arizona 85007		13. Type of Report and Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes

In cooperation with the U. S. Department of Transportation Federal Highway Administration

16. Abstract

This study had the objective of evaluating the effects of diluent additions and curing time after diluent addition on physical properties of asphalt-rubber mixtures. A single asphalt-rubber mixture composed of AR1000 asphalt and 25 percent Atlos TP044 rubber was studied. Four different percentages of diluent (Kerosene) and five different curing times at 140F were considered. Testing procedures utilized included ring and ball softening point, Schweyer Rheometer and force-ductility at 39.2F, and viscosity during mixing at 375F by Torque-Fork and Haake viscometer. A total of 17 measured or calculated parameters are reported and discussed.

Softening points and force-ductility loads and stresses at failure decrease with increasing diluent concentrations and increased cure time tends to decrease the softening effect of diluent, possibly due to diluent evaporation. Increased diluent concentration decreased apparent viscosity at 39.2F measured using the Schweyer Rheometer but cure time did not influence results. Strains and elongations at failure in the force-ductility test were not influenced by either diluent concentration or cure time. Creep compliance increases with increasing diluent concentration and increased cure time tends to decrease the softening effect of the diluent. Diluent additions resulted in only slight decreases in mixing viscosity at 375F as indicated by the Forque-Fork. These differences were not detected with the Haake viscometer.

17. Key Words	18. Distribution Statement
Asphalt-rubber, asphalt, viscosity, force-ductility, Schweyer Rheometer, Torque-Fork, Haake viscometer, diluent	No restrictions. Available to the public through the NTIS, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	133	

Form DOT F 1700.7 (8-69)

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1.0 EXPERIMENT DESCRIPTION

1.1 The objective of this experiment was to evaluate the effects of diluent (kerosene) additions and curing time on physical properties of asphalt-rubber mixtures.

1.2 A laboratory investigation which considered one asphalt-rubber formulation, four different percentages of diluent, and five curing times was performed.

1.2.1 The asphalt-rubber mixture used was representative of that currently used by a major asphalt-rubber supplier. This mixture is composed of AR1000 asphalt and 25 percent Atlos TPO44 ambient grind tread peel rubber. Characteristics of AR1000 asphalt and TPO44 rubber used are contained in the project Summary Report (1). During commercial production of this asphalt-rubber mixture, diluents are commonly added to reduce mixture viscosity just prior to application.

1.2.2 Four different percentages of diluent were studied - 0, 2, 4, and 6 percent by total weight of asphalt-rubber mixture. Diluent used was Chevron 410-H.

1.3.3 Five different curing times at 140F (60C) were used - 0, 1, 4, 24, and 168 hours.

1.3.4 Asphalt-rubber mixtures were all prepared using a standard mixing procedure at 375F (191C) in the Arizona Torque-Fork. Details of the procedure are found in the project Summary Report.

1.3 Materials properties assessed in this study are:

- Ring and ball softening point
- Apparent viscosity and shear rate sensitivity by the Schweyer Rheometer at 39.2F (4C)
- Stress, strain, and creep compliance properties at 39.2F (4C) using Force-Ductility
- Viscosity during mixing at 375F (191C) using the Arizona Torque-Fork
- Viscosity during mixing at 375F (191C) using the Haake Rotational Viscometer.

1.3.1 A total of 17 different parameters were evaluated, analyzed, and reported. Details of testing procedures used are found in the project Summary Report (1).

2.0 EXPERIMENTAL DESIGN AND DATA ANALYSIS.

2.1 The experiment was designed as a completely randomized two factor fixed factorial with two replications per cell.

2.1.1 The experimental matrix is shown in Figure 1.

2.1.2 The fixed factor model is:

$$Y_{ijk} = \mu + C_i + T_j + (CT)_{ij} + \varepsilon_{(ij)k}$$

in which:

Y_{ijk} = Response variable (softening point, Schweyer constants, etc.) for the ith level of diluent concentration, j^{th} level of curing time, and k^{th} replication.

μ = Effect of overall mean

C_i = Effect of diluent concentration

T_j = Effect of curing time

$(CT)_{ij}$ = Effect of diluent concentration-cure time interaction

$\varepsilon_{(ij)k}$ = Experimental error.

2.1.3 Degrees of freedom for the analysis are as follows:

Source	Degrees of Freedom
C_i	3
T_j	4
$(CT)_{ij}$	12
Error	20
Total	39

2.1.4 Data were analayzed using conventional two-way analysis of variance techniques. Prior to analysis, homogeneity of variance was tested by the Foster and Burr q-test (2).

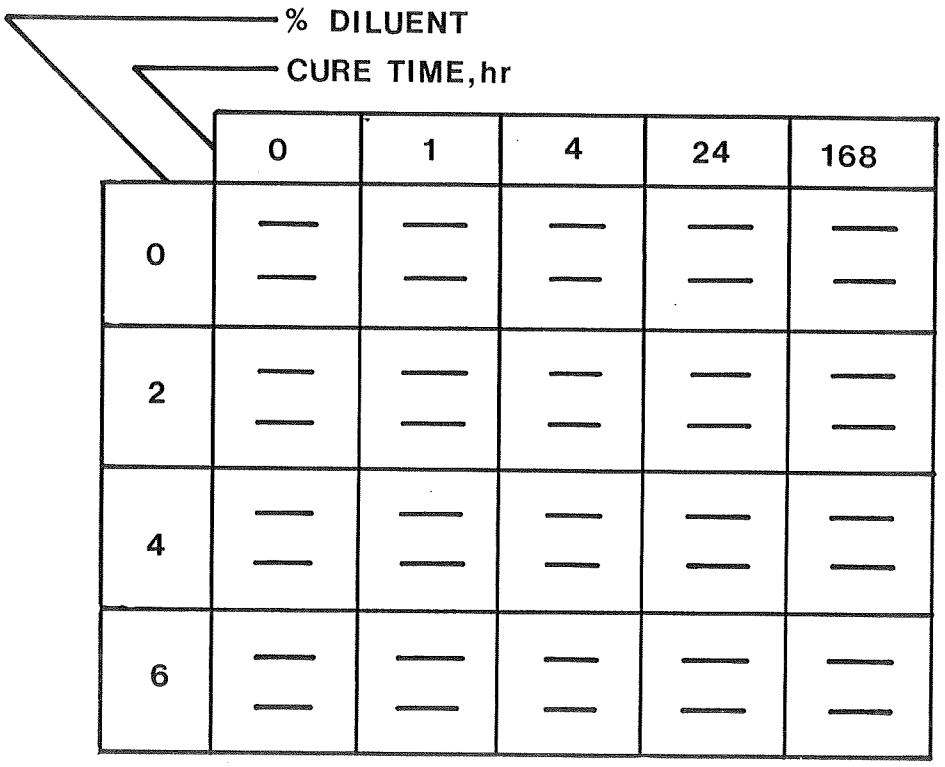

Figure 1 Experimental Test Matrix

2.2 Levels of independent variables.

2.2.1 Diluent concentration at 0, 2, 4, and 6 percent by weight of asphalt-rubber mixture.

2.2.2 Curing times of 0, 1, 4, 24, and 168 hours.

2.3 Following ANOVA, significant effects were ranked using the Newman-Keuls multiple range test (3).

3.0 CURING PROCEDURE

3.1 Curing of the asphalt-rubber mixtures was performed as follows:

A. Immediately after completion of mixing as described in the project Summary Report (1), pour the entire mixture from the mix bowl onto a 2' x 2' sheet of release paper.

B. Place 1/4 inch thick spacers on the release paper, place another sheet of release paper on top of the mixture, and then a flat 2' x 2' board on top of second sheet of the release paper. Downward pressure is then applied to the board by hand until the board contacts the spacers forming a 1/4 inch thick sheet of the asphalt-rubber mixture.

C. The mixture is cooled to room temperature and place horizontally in a gravity convection oven maintained at 140F (60C) for the appropriate cure duration.

D. Following curing, asphalt-rubber mixtures are cooled to room temperature and separated using a heated spatula into portions which are placed into 8 ounce storage tins which are placed in a freezer.

E. To prepare a mixed asphalt-rubber mixture for testing, an 8 ounce tin of the specific mixture was removed from the freezer and heated to 275F on a hotplate while constantly being stirred. When the material reached 275F, it was ready for specimen fabrication.

4.0 RESULTS AND DISCUSSIONS.

4.1 Ring and Ball Softening Point.

4.1.1 Measured and analyzed ring and ball softening point data are tabulated in Appendix A in Table A-1 and plotted in Figures A1 through A11.

4.1.2 The ANOVA summary for softening point is tabulated in Table A-2.

4.1.2.1 Diluent concentration, cure time, and the concentration-cure time interaction are significant effects at the 0.01 level.

4.1.3 Effect of Diluent. Newman-Keuls ranking of data shows the following ordering for each cure time by percent diluent:

Cure time, hours				
0	1	4	24	168
0*	0	0	0	0
2	6	2	2	6
4	2	4	4	2
6	4	6	6	4

*Note: 0, 2, 4, and 6 are percent 410-H.

| Signifies no significant difference.

The above ranking shows that at no curing, increasing diluent additions decrease softening point (85.4C at 0 percent diluent, 71.4C at 2 percent, and 63.3C average at 4 and 6 percent).

At 24 and 168 hours curing, softening point is not affected by percent diluent (65.9C average at 24 hours curing and 72.4C average at 168 hours). These trends can be seen in Figure A1 through A6.

4.1.4 Effect of Cure Time - Newman-Keuls ranking for each diluent percentage by cure time is:

Diluent Concentration, %			
0	2	4	6
0*	0	168	168
168	168	4	1
24	4	24	0
4	24	0	24
1	1	1	4

*Note: 0, 1, 4, 24, and 168 are cure time in hours.

| Signifies no significant difference.

The above ranking shows that at 0 percent diluent, curing lowered the softening point (85.4C for no cure compared to a 73.0C average for the four other cure times investigated). At 2 percent diluent, no differences were found in softening point with cure time (67.4C average).

At 4 and 6 percent diluent, the 168 hour cure resulted in the highest mean softening points. These trends can be seen in Figures A7 through A11.

4.2 Schweyer Rheometer Constant, G-tube.

4.2.1 Measured rheometer constants using the G-tube are tabulated in Appendix B in Table B-1.

4.2.2 The measured data did not require transformations to provide for variance homogeneity prior to analysis. Analyzed data are plotted in Appendix B, Figures B1 through B6.

4.2.3 The ANOVA summary for rheometer constant G-tube data is tabulated in Table B-2.

4.2.3.1 Diluent concentration was significant at the 0.05 level but not at the 0.01 level. Cure time and the concentration-cure time interaction were not significant at the 0.05 level.

4.2.4 Effect of Diluent. Average shear susceptibility constants in the G tube for all cure times are 0.502 at 0 percent diluent, 0.654 at 2 percent, 0.684 at 4 percent, and 0.536 at 6 percent.

4.3 Schweyer Rheometer Constant, F-tube.

4.3.1 Measured rheometer constants using the F-tube are tabulated in Appendix C in Table C-1 and plotted in Figure C1.

4.3.2 Measured data did not require transformation to provide for variance homogeneity for analysis.

4.3.3 The ANOVA summary for rheometer constant, F-tube, is tabulated in Table C-2.

4.3.3.1 Neither of the main effects or the interaction were significant at the 0.05 level.

4.3.4 Analysis indicates that shear susceptibility constants measured in the F-tube of asphalt-rubber mixtures tested were not influenced by diluent concentration or cure time. Overall average value was 1.04 indicating that mixtures tested were very close to being Newtonian in nature.

4.4 Schweyer Rheometer Apparent Viscosity ($\eta_{0.05}$) at 39.2F (4C), G-tube

4.4.1 Measured apparent viscosity data using the G-tube are tabulated in Appendix D in Table D-1 and plotted in Figures D1 through D6.

4.4.2 Measured data did not require transformation to provide for variance homogeneity for analysis.

4.4.3 The ANOVA summary for apparent viscosity, G-tube is tabulated in Table D-2.

4.4.3.1 Diluent concentration was significant at the 0.01 level. Cure time and the concentration-cure time interaction were not significant at the 0.05 level.

4.4.4 Average viscosities in the G-tube for all cure times are 37.7 x 10^6 Pa-s at 0 percent diluent, 27.8 x 10^6 Pa-s at 2 percent, 15.9 x 10^6 Pa-s at 4 percent, and 11.5 x 10^6 Pa-s at 6 percent. Newman-Keuls analysis of data collapsed across cure time shows that viscosity results at 0 and 2 percent diluent are the same, and that results at 2, 4, and 6 percent are the same.

4.5 Schweyer Rheometer Apparent Viscosity ($\eta_{0.05}$) at 39.2F (4C), F-tube

4.5.1 Measured apparent viscosity data using the F-tube are tabulated in Appendix E in Table E-1 and plotted in Figures E1 through E6.

4.5.2 Measured data did not require transformation to provide for variance homogeneity for analysis.

4.5.3 The ANOVA summary for apparent viscosity, F-tube is tabulated in Table E-2.

4.5.3.1 Diluent concentration was significant at the 0.01 level. Cure time and the concentration-cure time interaction were not significant at the 0.05 level.

4.5.4 Average viscosities in the F-tube for all cure times are 215.7 x 10^6 Pa-s at 0 percent diluent, 92.9 x 10^6 Pa-s at 2 percent, 42.5 x 10^6 Pa-s at 4 percent, and 42.1 x 10^6 Pa-s at 6 percent. Newman-Keuls analysis of data collapsed across cure time shows that viscosity at 0 percent diluent is greater than that at 2, 4, and 6 percent diluent which are not different.

4.6 Force-Ductility Load at Failure at 39.2F (4C)

4.6.1 Measured force ductility load at failure data are tabulated in Appendix F in Table F-1. Three measurements were obtained for each matrix cell replicate.

4.6.2 Analyzed load at failure data are tabulated in Table F-2 and plotted in Figures F1 through F11. Each entry in Table F-2 is the mean of three measurements from Table F-1.

4.6.3 The ANOVA summary for force ductility load at failure is tabulated in Table F-3.

4.6.3.1 Diluent concentration and cure time were significant effects at the 0.01 level. The concentration-cure time interaction was significant at the 0.05 level but not at the 0.01 level.

4.6.4 Effect of Diluent. Newman-Keuls ranking of data shows the following ordering for each cure time by percent diluent:

Cure time, hours				
0	1	4	24	168
0*	0	0	0	0
2	2	2	2	6
4	4	4	4	2
6	6	6	6	4

*Note: 0, 2, 4, and 6 are percent 410-H.

| Signifies no significant difference.

The above ranking shows that as diluent concentration increases for each curing time, that mean load at failure decreases.

For the no cure condition, load at failure for 0 percent diluent was 23.7 lb. compared to a 5.7 lb. average for the 2, 4, and 6 percent diluent mixtures. For the 168 hour cure, load at failure for 0 percent diluent was 23.5 lb compared to a 15.1 lb average for the 2, 4 and 6 percent diluent mixtures. These trends can be seen in Figures F1 through F6.

4.6.5 Effect of Cure Time. Newman-Keuls ranking for each diluent percentage by cure time is:

Diluent Concentration, %			
0	2	4	6
0*	168	168	168
168	24	4	24
4	4	24	0
24	1	1	1
1	0	0	4

*Note: 0, 2, 4, 24, and 168 are cure time hours.

| Signifies no significant differences.

This ranking indicates that at 0 percent diluent, load at failure is not influenced by cure time (average 21.1 lb), but, with 2, 4, and 6 percent diluent, load at failure is significantly influenced by cure time in that as cure time increases, load at failure increases. This effect is more pronounced at higher diluent concentration (4 and 6 percent) than low (2 percent). For asphalt-rubber mixtures containing 4 and 6 percent diluent, between 24 and 168 hours of curing were required for loads at failure to significantly increase. At 2 percent diluent, increases in load at failure were significant between 1 and 4 hours of curing. These trends can be seen in Figures F7 through F11.

4.7 Force-Ductility Elongation at Failure at 39.2F (4C)

4.7.1 Measured force ductility elongation at failure data are tabulated in Appendix G in Table G-1. Three measurements were obtained for each matrix cell replicate.

4.7.2 Reduced elongation at failure data which were analyzed are tabulated in Table G2 and plotted in Figure G1. Each entry in Table G-2 is the mean of three values from Table G-1.

4.7.3 The ANOVA summary for elongation at failure is tabulated in Table G-3.

4.7.3.1 Neither of the main effects or the interaction were significant at the 0.05 level.

4.7.4 Analysis indicates that elongation at failure at 39.2F is not influenced by percent diluent or cure time. Average elongation at failure for mixtures tested is 174.6mm.

4.8 Force-Ductility Engineering Stress at Failure at 39.2F (4C)

4.8.1 Calculated engineering stress at failure data are tabulated in Appendix H in Table H-1. Three determinations were obtained for each matrix cell replication.

4.8.2 Reduced engineering stress at failure data which were analyzed are tabulated in Table H-2 and plotted in Figures H1 through H11. Each entry in Table H-2 is the mean of three values in Table H-1.

4.8.3 The ANOVA summary for engineering stress at failure is tabulated in Table H-3.

4.8.3.1 Diluent concentration and cure time are significant effects at the 0.01 level. The concentration-cure time interaction is significant at the 0.05 level but not at the 0.01 level.

4.8.4 Effect of Diluent. Newman-Keuls ranking of data at each cure time by percent diluent shows the same ordering as for load at failure (Section 4.6.4 of this report). Similar discussions regarding effects of diluent apply.

4.8.5 Effect of Cure Time. Newman-Keuls ranking of data for each percent diluent by cure time shows the same ordering as for load at failure (Section 4.6.5 of this report). Similar discussions regarding effects of cure time apply.

4.9 Force-Ductility Engineering Strain at Failure at 39.2F (4C)

4.9.1 Calculated engineering strain at failure values are tabulated in Appendix I in Table I-1. Three determinations were obtained for each matrix cell replication.

4.9.2 Reduced engineering strain at failure data which were analyzed are tabulated in Table I-2 and are plotted in Figure I1. Each entry in Table I-2 is the mean of three values from Table I-1.

4.9.3 The ANOVA summary for engineering strain at failure is tabulated in Table I-3.

4.9.3.1 Neither of the main effects or the interaction were significant at the 0.05 level.

4.9.4 Analysis indicates that engineering strain at failure at 39.2F (4C) is not influenced by percent diluent or cure time. Average engineering strain at failure for mixtures tested is 3.30 mm/mm.

4.10 Force-Ductility True Stress at Failure at 39.2F (4C)

4.10.1 Calculated force-ductility true stress at failure data are tabulated in Appendix J in Table J-1. Three determinations were obtained for each matrix cell replication.

4.10.2 Analyzed true stress at failure data are tabulated in Appendix J in Table J-2 and plotted in Figures J1 through J11. Each entry in Table J-2 is the mean of three values from Table J-1.

4.10.3 The ANOVA summary for true stress at failure data is tabulated in Table J-3.

4.10.3.1 Diluent concentration and cure time are significant effects at the 0.01 level. The concentration-cure time interaction is not significant at the 0.05 level.

4.10.4 Effect of Diluent. Newman-Keuls ranking of data for each cure time by percent diluent shows the following ordering:

Cure time, hours				
0	1	4	24	168
0*	0	0	0	0
2	2	2	2	2
4	4	4	4	4
6	6	6	6	6

*Note: 0, 2, 4, and 6 are percent 410-H.

| Signifies no significant difference.

The above ranking shows that as diluent concentration increases at each cure time, true stress at failure decreases.

For the no cure condition at 0 percent diluent, true stress at failure was 618 psi, compared to a 164 psi average for mixtures containing 2, 4, and 6 percent diluent. For the 168 hour cure, average true stress at failure was 507 psi for mixtures containing 0, 2, and 4 percent diluent.

4.10.5 Effect of Cure Time. Newman-Keuls ranking of data for each percent diluent by cure time shows the following ordering:

Percent Diluent			
0	2	4	6
168*	168	168	168
0	24	24	24
4	4	4	0
24	1	1	1
1	0	0	4

*Note: 0, 1, 4, 24, and 168 are cure time hours.

| Signifies no significant differences.

The above ranking shows that at 0 and 2 percent diluent, true stress at failure is not influenced by cure time (587.8 psi average at 0 percent and 337.2 psi at 2 percent). With 4 and 6 percent diluent, true stress at failure is significantly influenced by cure time in that as cure time increases, true stress at failure increases. For asphalt-rubber mixtures containing 4 and 6 percent diluent, between 24 and 168 hours of curing were required for loads at failure to significantly increase.

4.11 Force-Ductility True Strain at Failure at 39.2F (4C)

4.11.1 True strain at failure data are tabulated in Appendix K in Table K-1. Three determinations were obtained for each matrix cell replication.

4.11.2 Analyzed true strain at failure data are tabulated in Appendix K in Table K-2 and plotted in Figure K1. Each entry in Table K-2 is the mean of three values from Table K-1.

4.11.3 The ANOVA summary for true strain at failure is tabulated in Table K-3.

4.11.3.1 Neither of the main effects or the interaction were significant at the 0.05 level.

4.11.4 Analysis shows that true strain at failure is not influenced by diluent concentration or cure time. Average true strain at failure is 1.4. mm/mm.

4.12 Force-Ductility Engineering Creep Compliance at Failure at 39.2F (4C)

4.12.1 Engineering creep compliance data are tabulated in Appendix L in Table L-1. Three determinations were made for each matrix cell replication.

4.12.2 Reduced engineering creep compliance at failure data which were analyzed are tabulated in Table L-2 and plotted in Figures L1 through L6. Each entry in Table L-2 is the mean of three values from Table L-1.

4.12.3 The ANOVA summary for engineering creep compliance at failure is tabulated in Table L-3.

4.12.3.1 Diluent concentration, cure time, and the concentration-cure time interaction are significant effects at the 0.01 level.

4.12.4 Effect of Diluent - Newman Keuls ranking of data for each cure time by percent diluent shows the following ordering:

Cure time, hours				
0	1	4	24	168
6*	6	6	4	6
4	4	4	6	4
2	2	2	2	2
0	0	0	0	0

*Note: 0, 2, 4, and 6 are percent 410-H.

| Signifies no significant difference.

At 0, 1, and 4 hours of curing, asphalt-rubber mixtures containing 6 percent diluent had higher engineering creep compliance at failure values than mixtures containing 0, 2, or 4 percent diluent. At 24 and 168 hours of curing, engineering creep compliance at failure was not influenced by percent diluent.

4.12.5 Effect of Cure Time - Newman-Keuls ranking of data for each percent diluent by cure time shows the following ordering:

Percent Diluent			
0	2	4	6
24*	0	0	1
4	1	24	4
1	4	1	0
168	24	4	24
0	168	168	168

*Note: 0, 1, 4, 24, and 168 are cure time hours.

| Signifies no significant differences.

At 0, 2, and 4 percent diluent, cure time did not influence results (average values of 0.0264 psi^{-1} at 0 percent 410-H, 0.0513 at 2 percent, and 0.0883 at 4 percent). At 6 percent diluent, increasing cure times decreased engineering creep compliance at failure (0.1866 psi^{-1} average at 0, 1, and 4 hour cures compared to 0.0579 psi^{-1} at 24 and 168 hour cures).

4.13 Force-Ductility True Creep Compliance at Failure at 39.2F (4C)

4.13.1 Calculated true creep compliance data are tabulated in Appendix M in Table M-1. Three determinations were made for each matrix cell replication.

4.13.2 Analyzed true creep compliance data are tabulated in Table M-2 and plotted in Figures M1 through M6. Each entry in Table M-2 is the mean of three values in Table M-1 times 100. Data were multiplied by 100 for analysis to reduce error due to truncation of very small numbers during calculations.

4.13.3 The ANOVA summary for true creep compliance at failure is tabulated in Table M-3.

4.13.3.1 Diluent concentration, cure time, and the concentration-cure time interaction are significant effects at the 0.01 level.

4.13.4 Effect of Diluent Newman-Keuls ranking of data for each cure time by percent diluent shows the following ordering:

Cure time, hours				
0	1	4	24	168
6*	6	6	6	6
4	4	4	4	4
2	2	2	2	2
0	0	0	0	0

*Note: 0, 2, 4, and 6 are percent 410-H.

| Signifies no significant difference.

The above ranking shows that as diluent concentration increases, mean true creep compliance at failure increases. At 24 and 168 hours of cure, true creep compliance at failure is not influenced by percent diluent (0.00646 psi^{-1} average at 24 hours cure and 0.00334 psi^{-1} average at 168 hours cure).

At 0 hours of curing, no differences were noted for mixtures containing 2, 4, and 6 percent diluent (0.01062 psi^{-1} average). These mixtures had higher true creep compliance at failure than the mixture with 0 percent kerosene (0.000239 psi^{-1}). At each 1 and 4 hours of cure, differences between the 0, 2, and 4 percent diluent mixtures were not noted.

4.13.5 Effect of Cure Time - Newman-Keuls ranking of data for each percent diluent by cure time shows the following ordering:

Percent Diluent			
0	2	4	6
1*	0	0	4
24	1	1	1
4	4	24	0
168	24	4	24
0	168	168	168

*Note: 0, 1, 4, 24, and 168 are cure time hours.

| Signifies no significant differences.

The above ranking shows that at 0, 2, and 4 percent diluent, no differences exist in true creep compliance at failure (0.00264 psi^{-1} average at 0 percent 410-H, 0.000481 psi^{-1} average at 2 percent, and 0.00867 psi^{-1} average at 4 percent). At 6 percent diluent, longer cure periods resulted in lower true creep compliance at failure than shorter cure periods (0.000842 psi^{-1} average at 1 and 4 hours).

4.14 Force-Ductility Maximum True Creep Compliance at 39.2F (4C)

4.14.1 Maximum true creep compliance data are tabulated in Appendix N in Table N-1. Three determinations were made for each matrix cell replication.

4.14.2 Reduced maximum true creep compliance data are tabulated in Appendix N in Table N-2 and plotted in Figures N1 through N6. Each entry in Table N-2 is the mean of three values in Table N-1.

4.14.3 In order to comply with variance homogeneity requirements, log transformations of the data were required. Log transformed data are tabulated in Table N-3.

4.14.4 The ANOVA summary for maximum true creep compliance is tabulated in Table N-4.

4.14.4.1 Diluent concentration, cure time, and the concentration-cure time interaction are significant effects at the 0.01 level.

4.14.5 Effect of Diluent - Newman-Keuls ranking of data for each cure time by percent diluent shows the following ordering:

Cure time, hours				
0	1	4	24	168
6*	6	6	6	6
4	4	4	4	4
2	2	2	2	2
0	0	0	0	0

*Note: 0, 2, 4, and 6 are percent 410-H.

| Signifies no significant difference.

The above ranking shows that as percent diluent decreases mean maximum true creep compliance decreases. At 168 hours of cure, no differences due to percent diluent are noted (0.00471 psi^{-1} average), while at 0, 1, 4, and 24 hours of cure, differences are noted. For example, at 1 hour of cure, maximum true creep compliance for 6 percent diluent is 0.01907 psi^{-1} compared to 0.00420 psi^{-1} at 0 percent diluent.

4.14.6 Effect of Cure Time. Newman-Keuls ranking of data for each percent diluent by cure time shows the following ordering:

Percent Diluent			
0	2	4	6
24*	2	0	4
1	4	1	1
4	4	24	0
0	24	4	24
168	168	168	168

*Note: 0, 1, 4, 24, and 168 are cure time hours.

| Signifies no significant differences.

The above ranking shows that as percent diluent increases, cure time becomes a significant effect. At 0 percent diluent, no differences in maximum true creep compliance are noted (0.00264 psi^{-1} average). At 2, 4, and 6 percent diluent increased cure time decreases maximum true creep compliance. For example, at 6 percent diluent average true creep compliance at failure for 0, 1, and 4 hour cures is 0.01824 psi^{-1} compared to 0.00413 psi^{-1} at the 168 hour cure.

4.15 Force-Ductility Time to Maximum True Creep Compliance

4.15.1 Time to maximum true creep compliance data are tabulated in Appendix O in Table O-1. Three determinations were made for each matrix cell replication.

4.15.2 Analyzed time to maximum true creep compliance data are tabulated in Appendix N in Table O-2 and plotted in Figures O1 through O11. Each entry in Table O-2 is the mean of three values in Table O-1.

4.15.3 The ANOVA summary for time to maximum true creep compliance data is tabulated in Table O-3.

4.15.3.1 Diluent concentration and the concentration-cure time interaction are significant effects at the 0.01 level. Cure time is significant at the 0.05 level but not at the 0.01 level.

4.15.4 <u>Effect of Diluent Concentration</u>. Newman-Keuls ranking of data for each cure time by percent diluent shows the following ordering:

Cure time, hours				
0	1	4	24	168
4*	6	6	6	0
6	4	0	4	4
0	0	4	0	6
2	2	2	2	2

*Note: 0, 2, 4, and 6 are percent 410-H.

| Signifies no significant difference.

The above ranking shows that at 0, 24, and 168 hours of cure, time to maximum true creep compliance is not influenced by percent diluent (10.3 minute average at 0 hours of cure, 8.9 minute average at 24 hours, and 8.3 minute average at 168 hours). At 1 and 4 hours of cure, mixtures containing 6 percent diluent had longer times to maximum true creep compliance than mixtures containing 0, 2, or 4 percent diluent (at 1 hour of cure, 19.7 minutes at 6 percent diluent compared to a 9.3 minute average at 0, 2, and 4 percent diluent).

4.15.5 Effect of Cure Time. Newman-Keuls ranking of data for each percent diluent by cure time shows the following ordering:

Percent Diluent			
0	2	4	6
168*	0	0	4
4	1	1	1
1	4	24	0
0	24	4	24
24	168	168	168

*Note: 0, 1, 4, 24, and 168 are cure time hours.

| Signifies no significant differences.

The above ranking shows that at 0, 2, and 4 percent diluent, time to maximum true creep compliance is not influenced by cure time (8.4 minute average at 0 percent diluent, 7.8 minute average at 2 percent, and 10.6 minute average at 4 percent). At 6 percent diluent, mixtures which cured 1 and 4 hours (20.0 minute average) had longer times to maximum true creep compliance than mixtures which cured 0, 24, and 168 hours (9.5 minute average).

4.16 Arizona Torque-Fork Viscosity During Mixing at 375F (191C).

4.16.1 During mixing of the asphalt-rubber mixtures used in this study, differences in viscosity due to addition of diluent were measured using the Torque-Fork. The initial decrease in viscosity due to addition of diluent and the mixture viscosity after 1 hour of mixing are discussed. Since several mixtures at each percent diluent were formulated, data could be statistically analyzed.

4.16.2 Initial drop in mixture viscosity due to diluent addition data are tabulated in Appendix P in Table P-1.

4.16.2.1 One-way ANOVA (Table P-2) performed on decrease in viscosity data shows that percent diluent significantly affects viscosity decreases at the 0.01 level.

4.16.2.2 Average viscosity decreases due to diluent addition were 2.0 poise for 2 percent 410-H, 4.8 poise for 4 percent 410-H, and 6.3 poise for 6 percent 410-H.

4.16.3 Viscosity after 1 hour of mixing data are tabulated in Appendix P in Table P-3.

4.16.3.1 One-way ANOVA (Table P-4) performed on viscosity at 1 hour of mixing data shows that percent diluent significantly affects viscosity at the 0.05 level, but not at the 0.01.

4.16.3.2 Average viscosities at 1 hour of mixing are 38.0 poise for 0 percent diluent, 35.1 poise for 2 percent, 36.0 poise for 4 percent, and 32.0 poise for 6 percent.

4.17 Haake Viscosity During Mixing at 375F (191C).

4.17.1 Measured mixing viscosity data at 1 hour by the Haake viscometer are tabulated in Appendix Q in Table Q-1. Since several mixtures at each percent diluent were formulated, statistical analysis of the data was performed.

4.17.1.1 One-way ANOVA (Table Q-2) shows that percent diluent is not significant at the 0.05 level.

4.17.1.2 Analysis indicates that percent diluent does not significantly influence viscosity as measured by the Haake viscometer. Previous analyses indicate, however, that mixing viscosity differences, due to percent diluent, exist for the same mixtures as measured by the Torque-Fork. This difference may be related to the greater variability of the Haake viscosity data. (Haake, average coefficient of variation of 16.0 percent compared to 9.6 percent for the Torque-Fork at 1 hour of mixing).

5.0 CONCLUSIONS

5.1 A summary of two-way ANOVA results is tabulated in Table 1. This table indicates if diluent concentration, cure time and the interaction significantly affect the test parameters studied. From Table 1, it is noted that diluent concentration and cure time are significant effects for (1) Ring and ball softening point, and (2) Force-ductility load and stress at failure as well as for creep compliance results. Elongation and strains at failure from the force-ductility test were not significantly affected by diluent concentration or cure time. Apparent viscosity measured with the Schweyer Rheometer varied with percent diluent but not with cure time.

5.2 Ring and ball softening points tend to decrease with increasing diluent concentrations and increased cure time tends to decrease the softening effect of the diluent, possibly due to diluent evaporation.

5.3 Increased diluent concentration decreases apparent viscosity at 39.2F as measured using the Schweyer Rheometer. Schweyer viscosity is not influenced by cure time.

5.4 Increased diluent concentration lowers load and stresses at failure in the force-ductility test. Increased cure time (24 to 168 hours at 140F) increases load and stresses at failure of asphalt-rubber mixtures which contain 2, 4, and 6 percent diluent.

5.5 Creep compliance of asphalt-rubber mixtures increase as diluent concentration increases (mixes become softer) and increased cure time tends to decrease the softening effect of the diluent, possibly due to diluent evaporation.

5.6 Diluent additions cause slight, but noticeable decreases in mixture viscosity at 375F as indicated by the Torque-Fork.

5.7 The Haake viscometer did not indicate mixture viscosity differences due to percent diluent.

Table 1 Summary of Significant Effects

EFFECT \ TEST PARAMETER	C	T	CT
Softening Point	Y	Y	Y
SCHWEYER RHEOMETER (39.2F)			
Constant(C), G-tube	Y	-	-
Constant(C), F-tube	-	-	-
App. Viscosity, G-tube	Y	-	-
App. Viscosity, F-tube	Y	-	-
FORCE DUCTILITY (39.2F)			
Load at Failure	Y	Y	Y
Elongation at Failure	-	-	-
Eng. Stress at Failure	Y	Y	Y
Eng. Strain at Failure	-	-	-
True Stress at Failure	Y	Y	-
True Strain at Failure	-	-	-
Eng. Creep Compliance	Y	Y	Y
True Creep Compliance	Y	Y	Y
Max.True Creep Compliance	Y	Y	Y
Time to Max.T.Creep Compl.	Y	Y	Y

*Note: Y = significant at the 0.05 level
- = not significant at the 0.05 level

References

1. Rosner, J. C. and Chehovits, J. G., "Chemical and Physical Properties of Asphalt-Rubber - Phase III - Project Summary Report, April, 1982.

2. Burr, I. W. and Foster, L. A., "A Test For Equality of Variances", Mimeograph Series No. 282, Statistics Department, Purdue University, Lafayette, Indiana, 1972.

3. Burr, I. W., Applied Statistical Methods, Academic Press, Inc., New York, 1974.

APPENDIX A

RING AND BALL SOFTENING POINT

Table A-1 Ring and Ball Softening Point, °C

a. Measured and Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	91.00	69.00	71.50	71.00	76.50
	79.75	71.25	70.00	73.75	78.75
2% 410 H	70.75	60.75	68.00	64.75	72.25
	72.00	60.75	71.00	63.25	70.00
4% 410 H	68.00	57.50	69.00	64.75	70.25
	61.00	58.25	68.75	67.25	68.50
6% 410 H	62.75	61.75	60.50	61.50	76.00
	61.50	71.50	56.75	60.50	67.25

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	85.38	70.13	70.75	72.38	77.63
	s	9.968	1.994	1.329	2.437	1.994
	cv	11.67	2.84	1.88	3.37	2.57
2% 410 H	$\bar{x}$	71.38	60.75	69.50	64.00	71.13
	s	1.108	0	2.658	1.329	1.994
	cv	1.55	0	3.82	2.08	2.80
4% 410 H	$\bar{x}$	64.50	57.88	68.88	66.00	69.38
	s	6.202	.665	.222	2.215	1.55
	cv	9.62	1.15	.32	3.36	2.23
6% 410 H	$\bar{x}$	62.13	66.63	58.63	61.00	71.63
	s	1.108	8.639	3.323	.886	7.753
	cv	1.78	12.97	5.67	1.45	10.82

Table A-2 ANOVA Summary, Ring and Ball Softening Point

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	761.39	253.80	24.67	3.10	4.94
Tj	4	406.63	101.66	9.88	2.87	4.43
(CT)ij	12	483.12	40.26	3.91	2.28	3.23
Error	20	205.78	10.29			
TOTAL	39	1856.92				

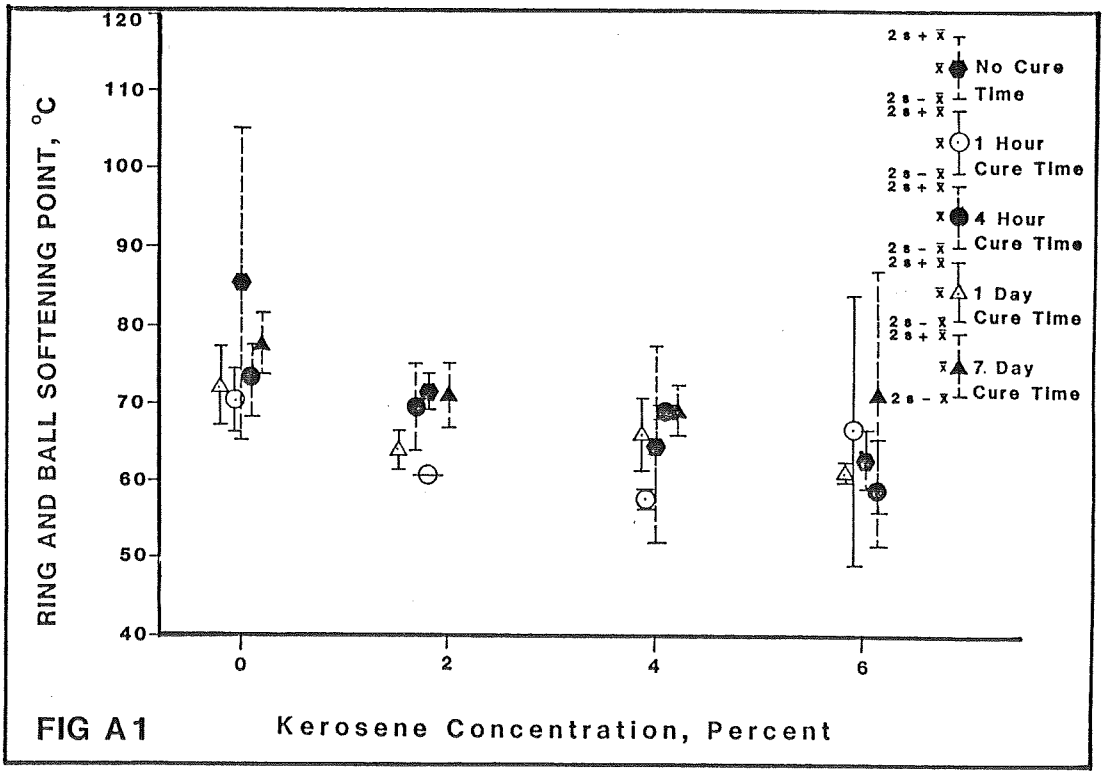

FIG A1

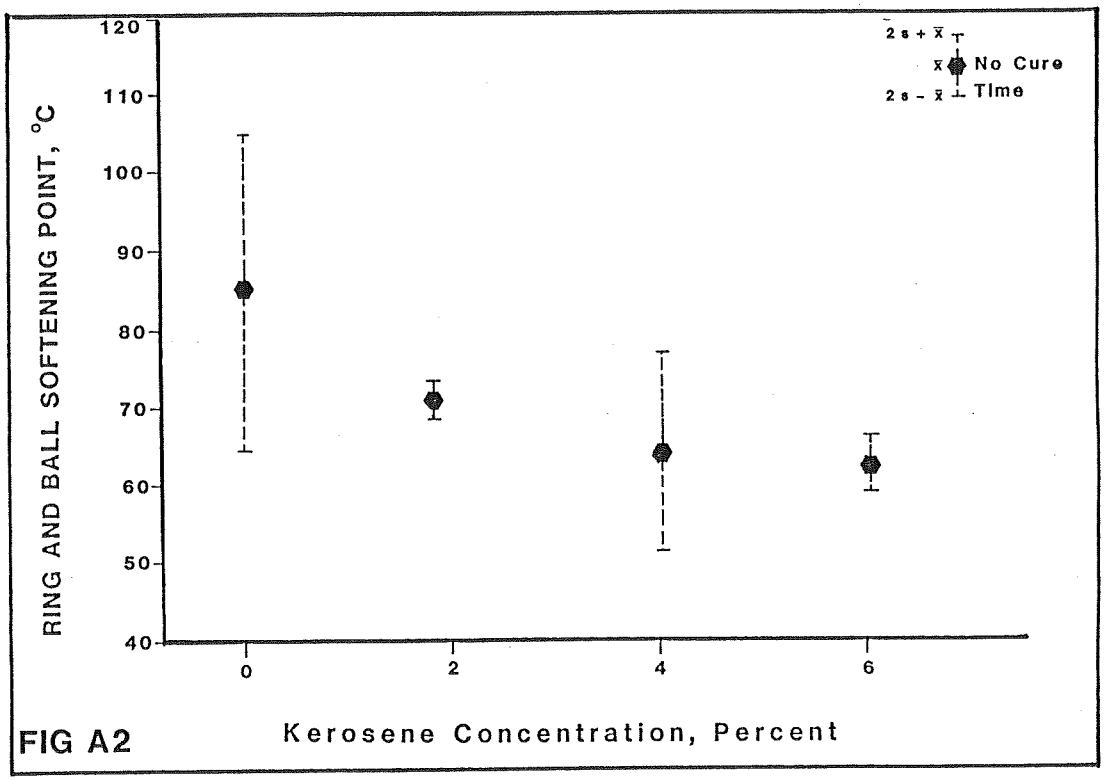
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
2
4
6
2s + x̄
x̄
2s − x̄
No Cure
Time
Kerosene Concentration, Percent

FIG A2

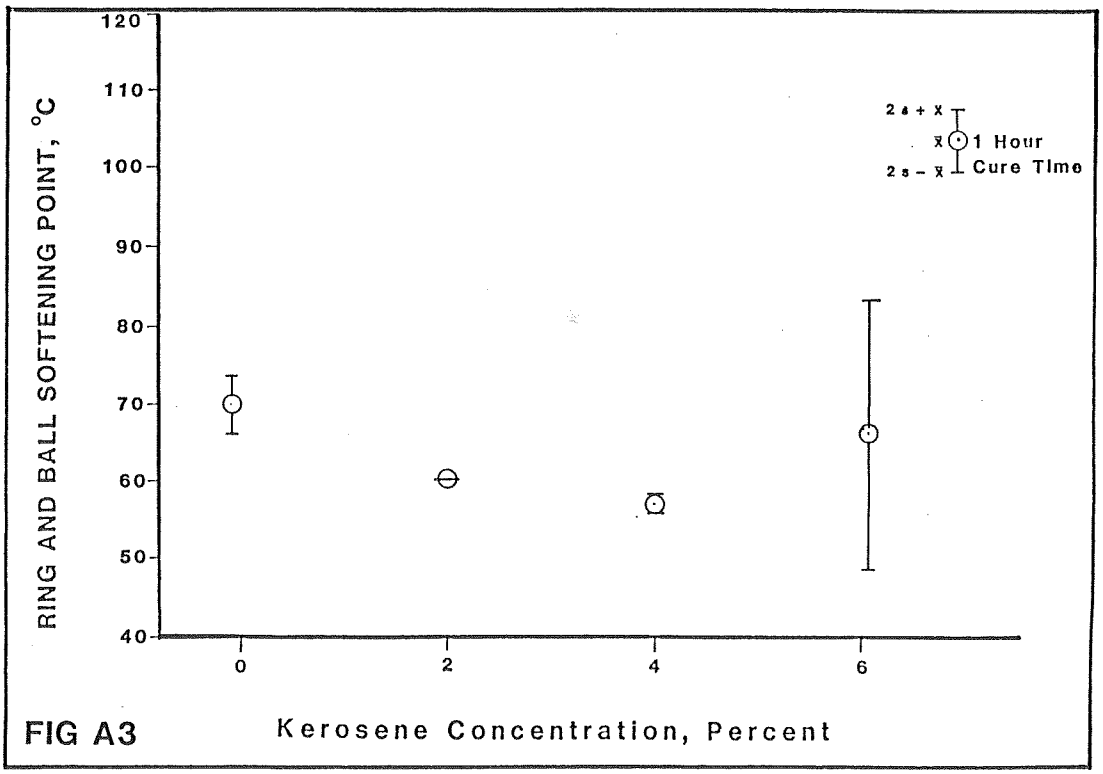
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
2
4
6
2s + x̄
x̄
2s − x̄
1 Hour
Cure Time
Kerosene Concentration, Percent

FIG A3

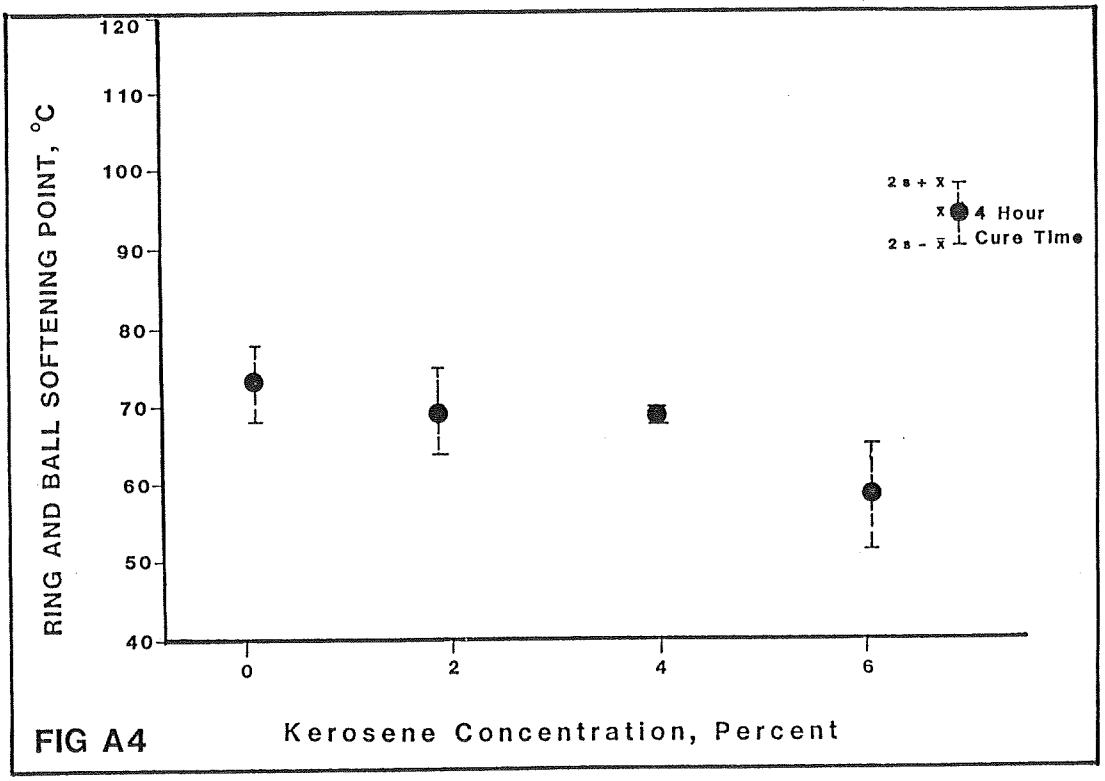
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
2
4
6
2s + x̄
x̄ 4 Hour
2s - x̄ Cure Time
Kerosene Concentration, Percent

FIG A4

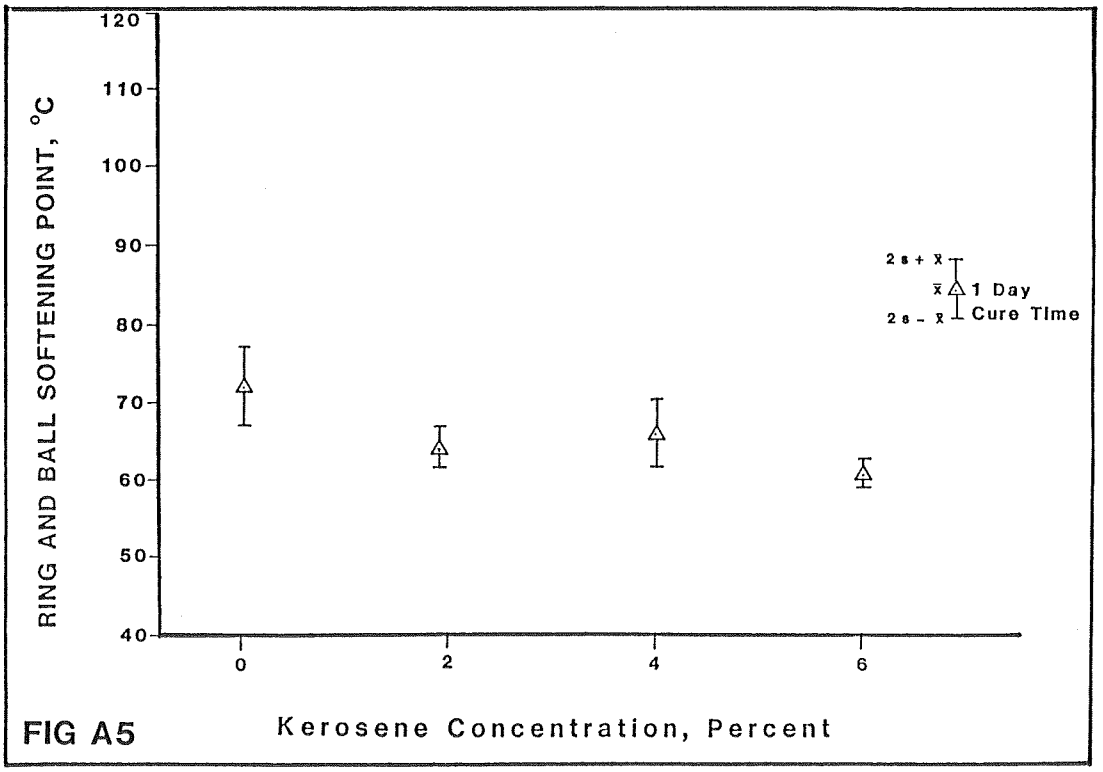
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
2
4
6
2s + x̄
x̄ 1 Day
2s - x̄ Cure Time
Kerosene Concentration, Percent

FIG A5

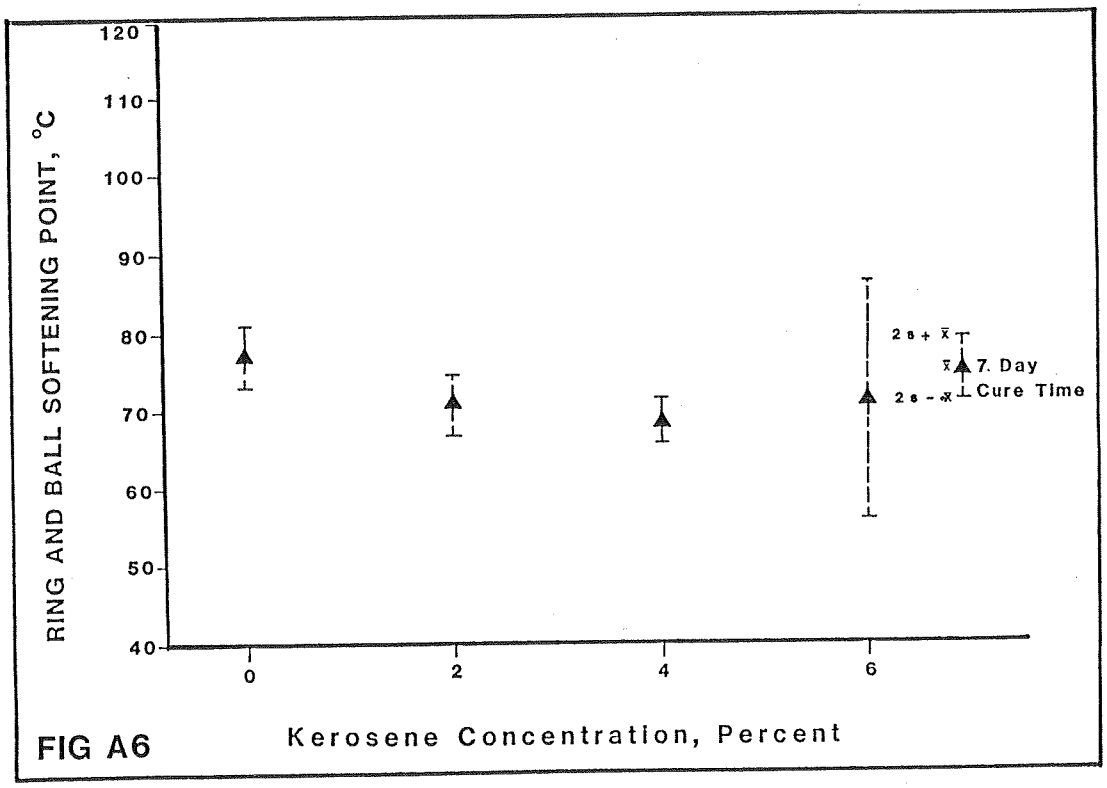
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
2
4
6
2 s + x̄
x̄
2 s - x̄
7. Day
Cure Time
Kerosene Concentration, Percent

FIG A6

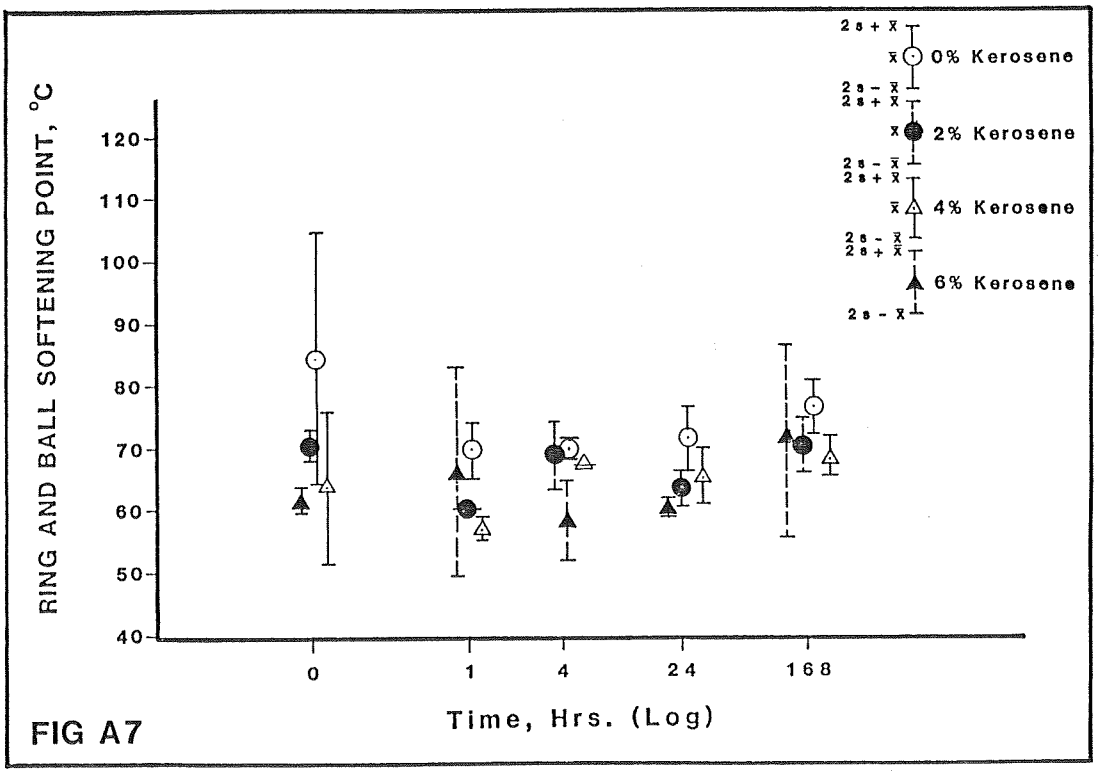
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
1
4
24
168
2 s + x̄
x̄
0% Kerosene
2 s - x̄
2 s + x̄
x̄
2% Kerosene
2 s - x̄
2 s + x̄
x̄
4% Kerosene
2 s - x̄
2 s + x̄
6% Kerosene
2 s - x̄
Time, Hrs. (Log)

FIG A7

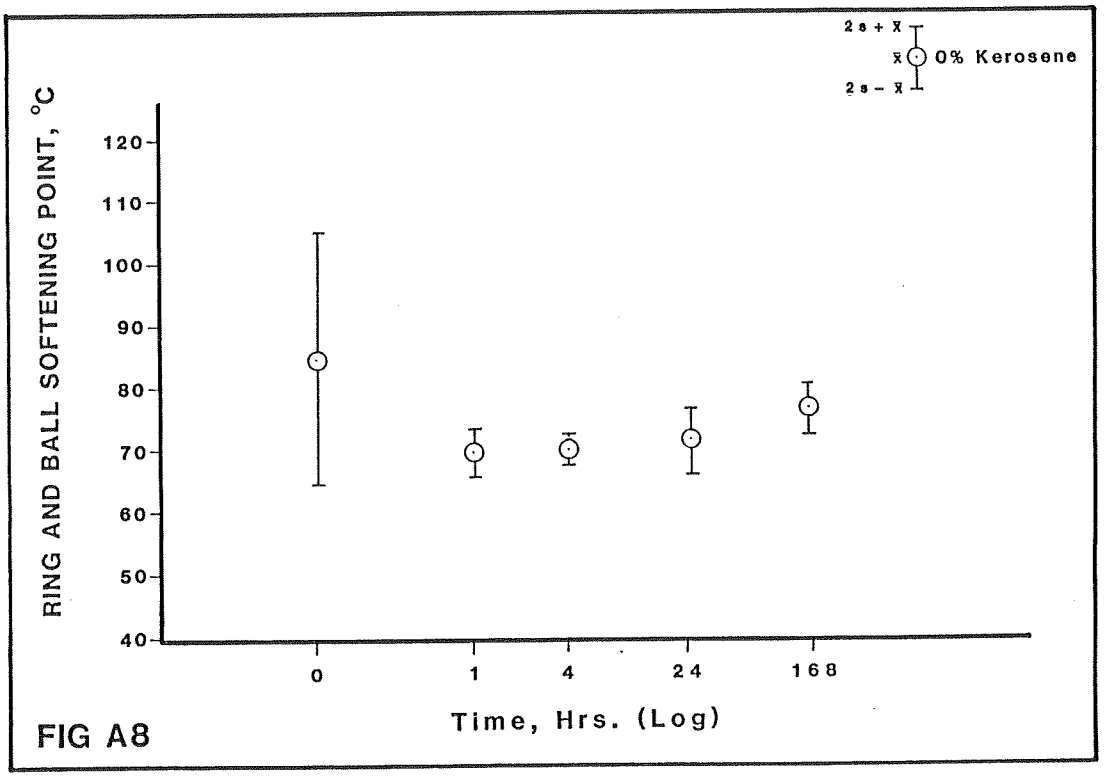
2s + x̄
x̄
2s - x̄
0% Kerosene
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
1
4
24
168
Time, Hrs. (Log)

FIG A8

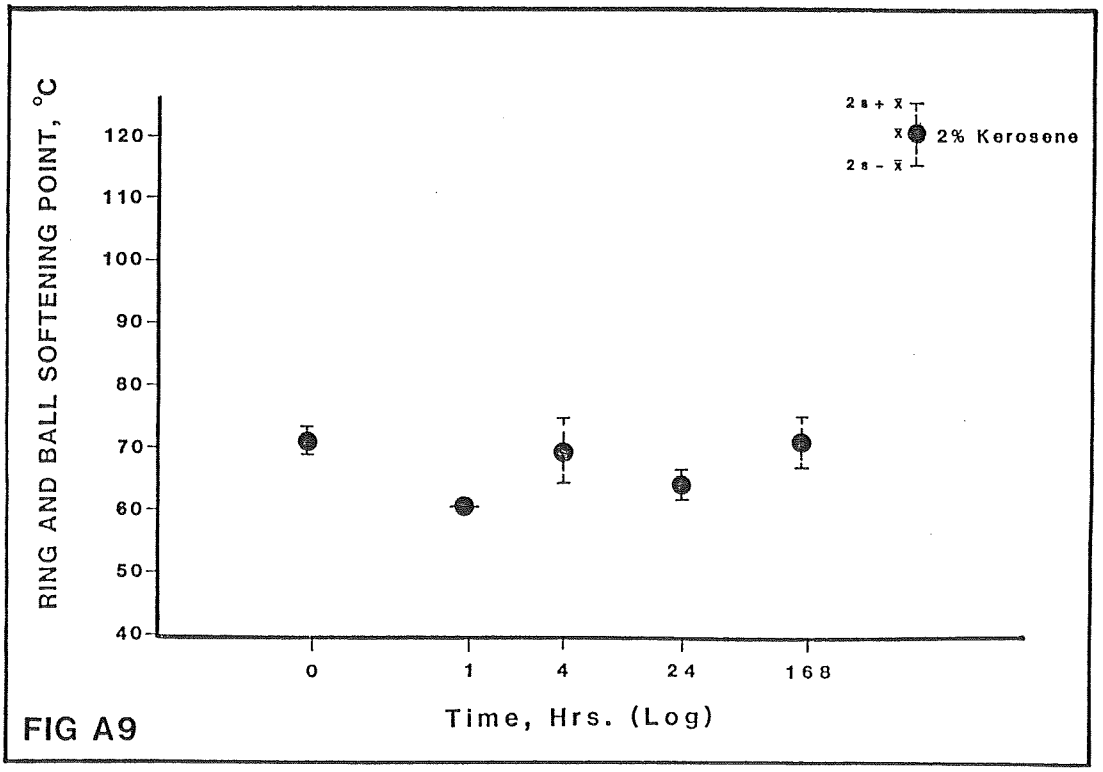
2s + x̄
x̄
2s - x̄
2% Kerosene
RING AND BALL SOFTENING POINT, °C
120
110
100
90
80
70
60
50
40
0
1
4
24
168
Time, Hrs. (Log)

FIG A9

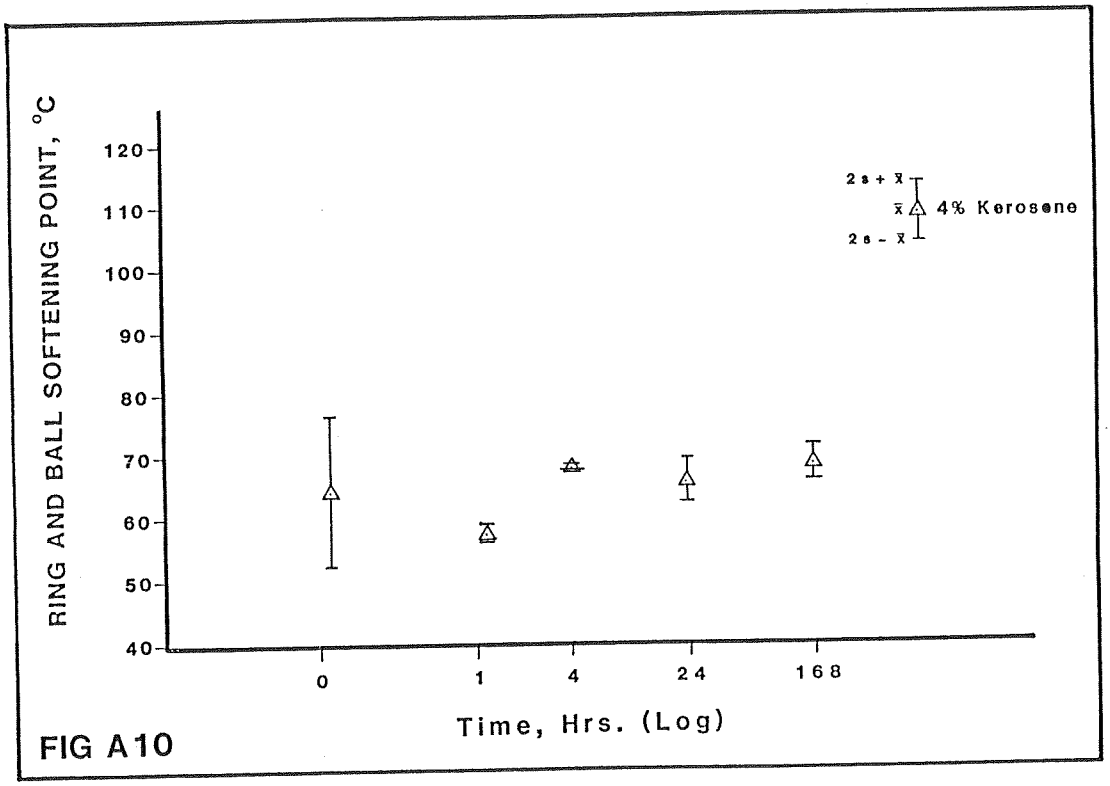

FIG A10

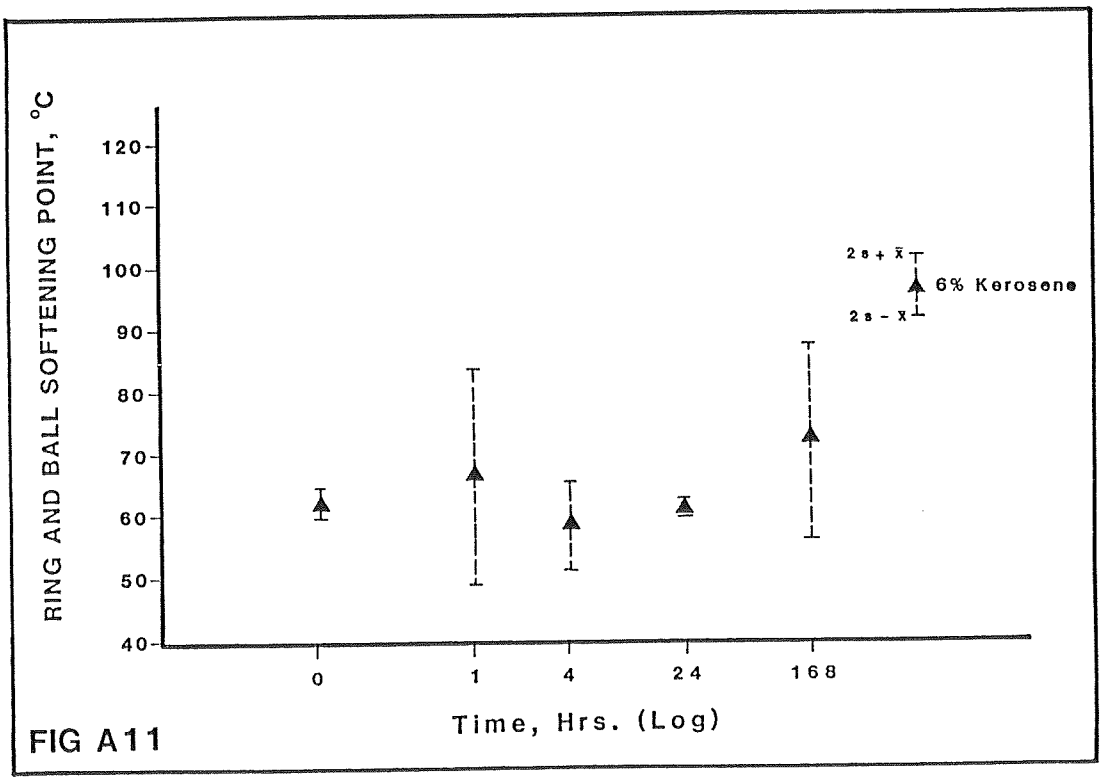

FIG A11

APPENDIX B

SCHWEYER RHEOMETER CONSTANT

(C), G-TUBE

Table B-1 Schweyer Rheometer Constant (C), G tube

a. Measured and Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.26 / .31	.50 / .78	.61 / .57	.70 / .51	.22 / .53
2% 410 H	.74 / .82	.70 / .68	.35 / .71	.70 / .87	.59 / .36
4% 410 H	.74 / .80	.86 / .37	.69 / .69	.71 / .79	.62 / .56
6% 410 H	.21 / .33	.63 / .65	.40 / .57	.55 / .66	.67 / .66

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.29	.64	.59	.61	.38
	s	.044	.248	.035	.168	.275
	cv	15.54	38.76	6.01	27.82	73.24
2% 410 H	$\bar{x}$	.78	.69	.53	.79	.48
	s	.071	.018	.319	.151	.204
	cv	9.09	2.57	60.18	19.19	42.90
4% 410 H	$\bar{x}$	.77	.62	.69	.75	.59
	s	.053	.434	0	.071	.053
	cv	6.90	70.59	0	9.45	9.01
6% 410 H	$\bar{x}$	.27	.64	.49	.61	.67
	s	.106	.018	.151	.097	.009
	cv	39.38	2.77	31.06	16.11	1.33

Table B-2 ANOVA Summary, Schweyer Rheometer Constant (C), G-tube

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	.24010	.08003	4.32	3.10	4.94
Tj	4	.16644	.04161	2.25	2.87	4.43
(CT)ij	12	.45998	.03833	2.07	2.28	3.23
Error	20	.37125	.01856			
TOTAL	39	1.23777				

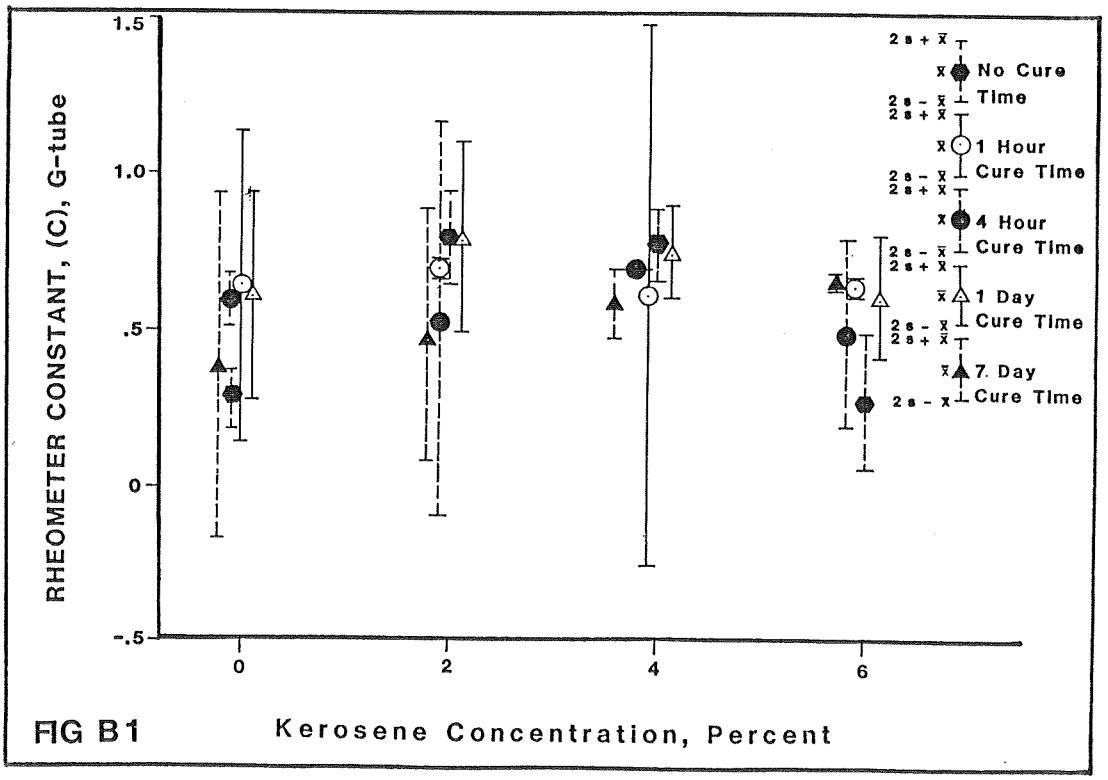

FIG B1

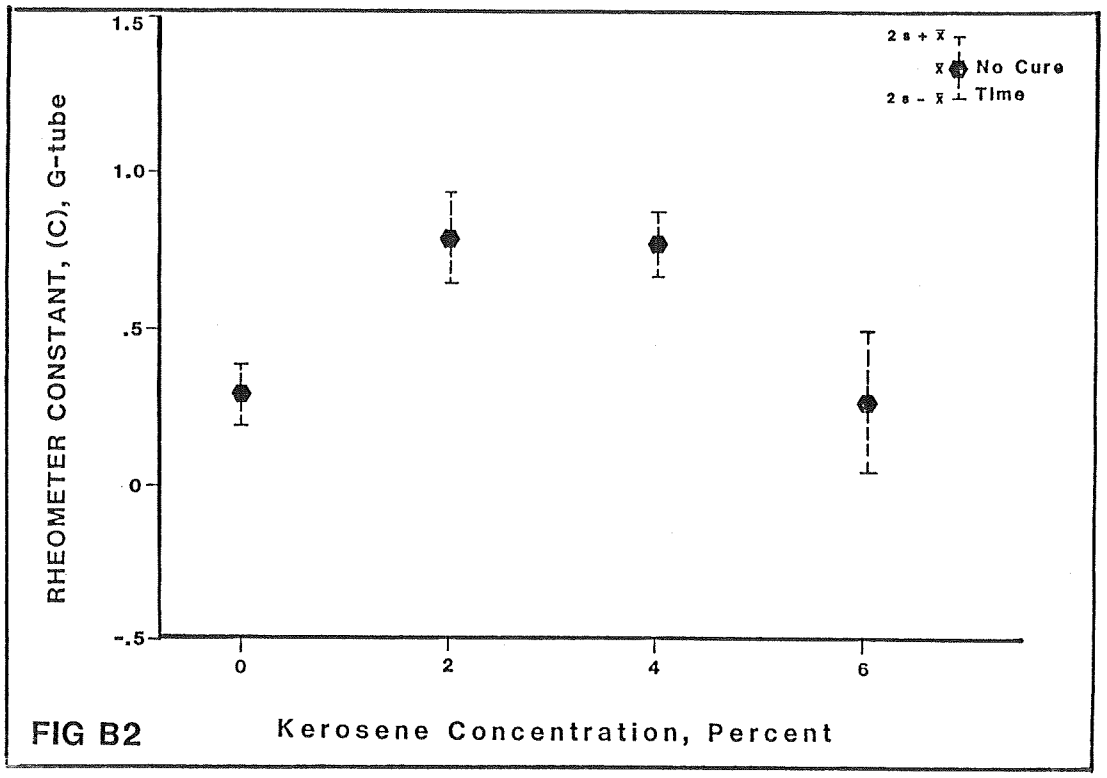
RHEOMETER CONSTANT, (C), G-tube
1.5
1.0
.5
0
-.5
0
2
4
6
2 s + x̄
x̄
2 s - x̄
No Cure
Time
Kerosene Concentration, Percent

FIG B2

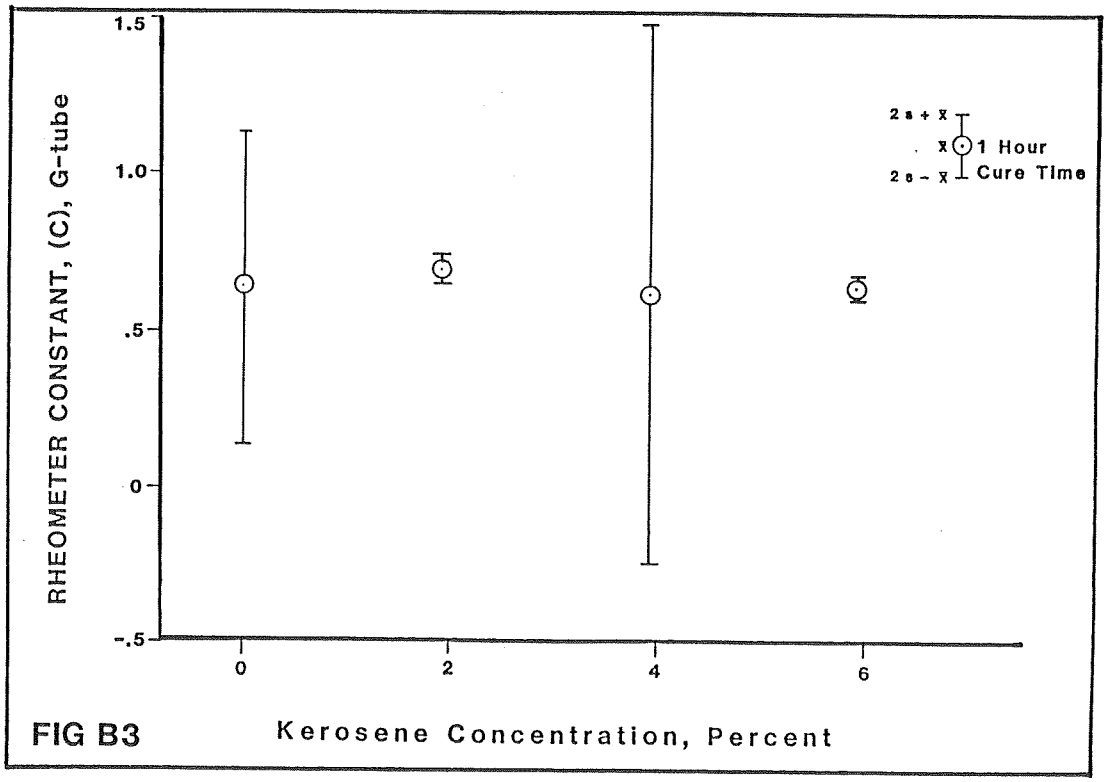
RHEOMETER CONSTANT, (C), G-tube
1.5
1.0
.5
0
-.5
0
2
4
6
2 s + x̄
x̄
2 s - x̄
1 Hour
Cure Time
Kerosene Concentration, Percent

FIG B3

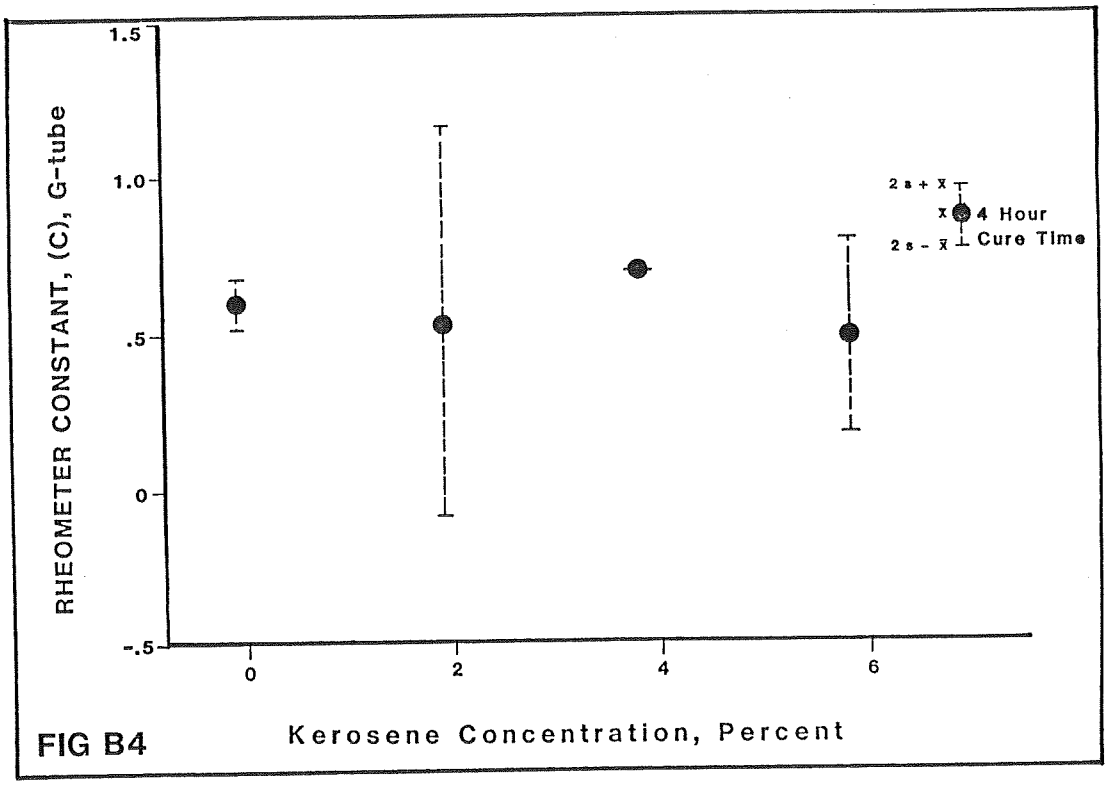
RHEOMETER CONSTANT, (C), G-tube
1.5
1.0
.5
0
-.5
0
2
4
6
2 s + x̄
x̄
2 s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG B4

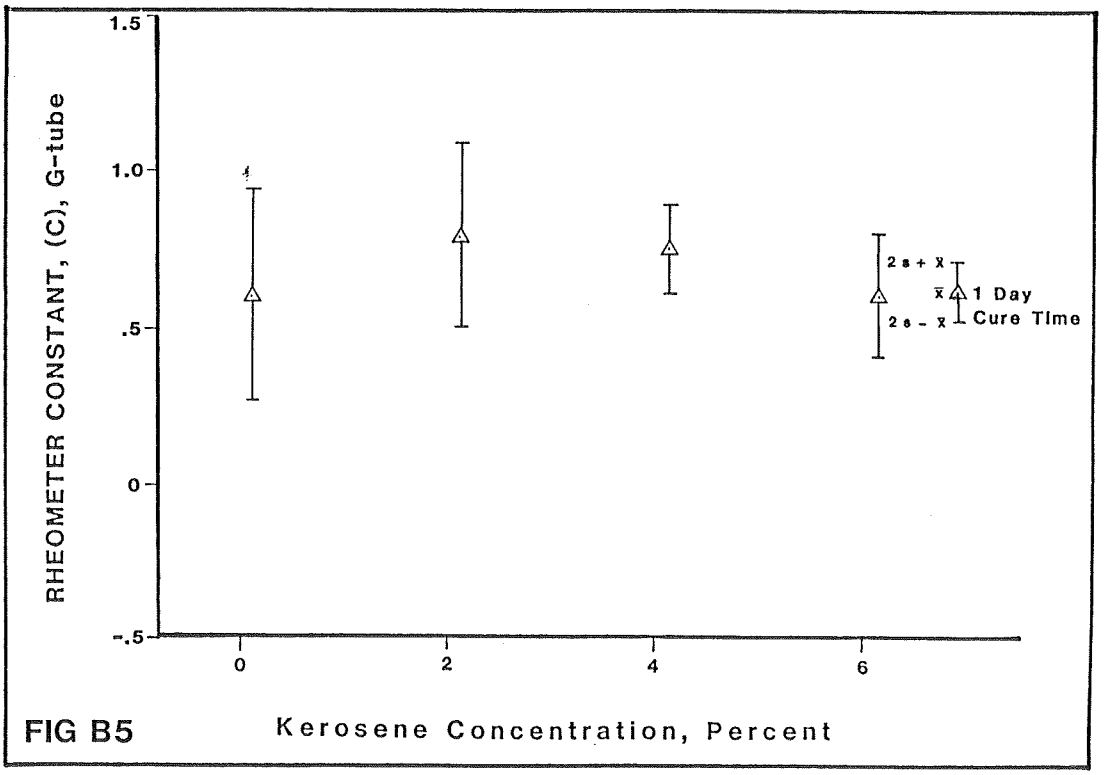
RHEOMETER CONSTANT, (C), G-tube
1.5
1.0
.5
0
-.5
0
2
4
6
2 s + x̄
x̄
2 s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG B5

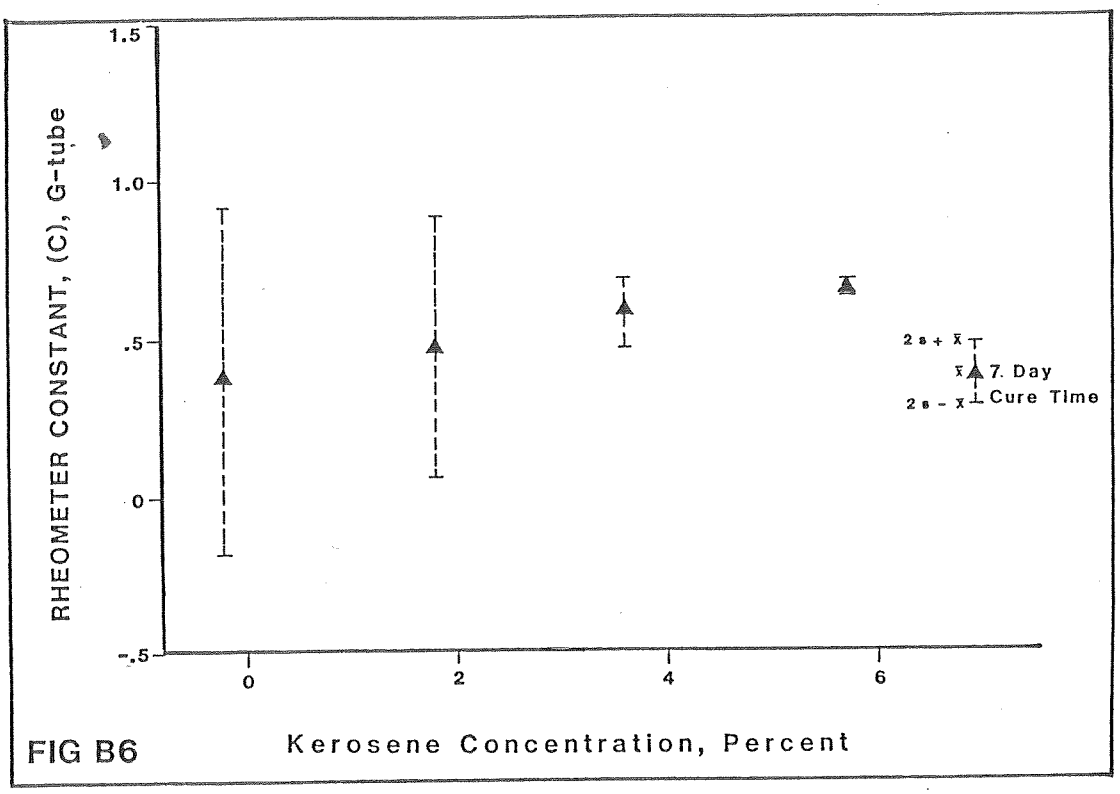
RHEOMETER CONSTANT, (C), G-tube
1.5
1.0
.5
0
-.5
0
2
4
6
2 s + x̄
x̄
2 s - x̄
7. Day
Cure Time
Kerosene Concentration, Percent

FIG B6

APPENDIX C

SCHWEYER RHEOMETER CONSTANT

(C), F-TUBE

Table C-1 Schweyer Rheometer, Constant (C), F-tube

a. Measured and Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.20 / .85	.95 / .98	1.2 / .86	1.0 / .72	.28 / .72
2% 410 H	.80 / 1.0	.75 / .82	.39 / 1.0	1.2 / .89	.98 / .89
4% 410 H	.69 / .96	.84 / .95	.91 / 1.0	.86 / .94	.94 / .72
6% 410 H	.47 / .70	.70 / .44	.64 / .76	.90 / .93	1.1 / .89

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.525	.965	1.030	.860	.500
	s	.57590	.02658	.30124	.24808	.38984
	cv	109.70	2.75	29.25	28.85	77.97
2% 410 H	$\bar{x}$	.900	.785	.695	1.045	.935
	s	.17720	.06202	.54046	.27466	.07974
	cv	19.69	7.90	77.76	26.28	8.53
4% 410 H	$\bar{x}$	.825	.895	.955	.900	.830
	s	.23922	.09746	.07974	.07088	.19492
	cv	30.00	10.89	8.35	7.88	23.48
6% 410 H	$\bar{x}$	.585	.570	.700	.915	.995
	s	.20378	.23036	.10632	.02658	.18606
	cv	34.83	40.41	15.19	2.91	18.70

Table C-2 ANOVA Summary, Schweyer Rheometer Constant (C), F-tube

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	.128490	.04283	1.03	3.10	4.94
Tj	4	.203115	.05078	1.22	2.87	4.43
(CT)ij	12	.759185	.06327	1.52	2.28	3.23
Error	20	.830000				
TOTAL	39	1.920790				

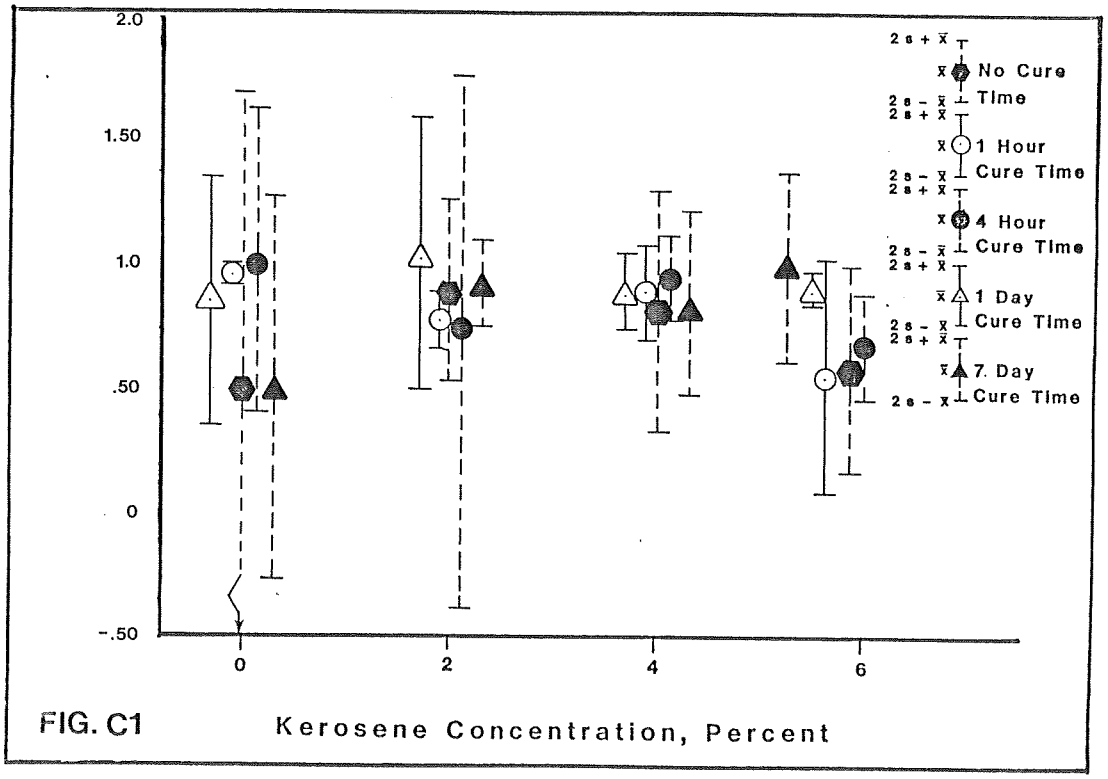

FIG. C1

APPENDIX D

VISCOSITY ($\eta_{0.05}$) BY SCHWEYER RHEOMETER AT 39.2F (4C), G-TUBE

Table D-1 Schweyer Rheometer Apparent Viscosity, $\eta_{0.05}$, 10^6 Pa-s, G-tube

a. Measured and Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	5.0 / 13.0	15.0 / 69.0	45.0 / 64.0	77.0 / 30.0	12.0 / 47.0
2% 410 H	26.0 / 48.0	20.0 / 16.0	2.3 / 41.0	42.0 / 45.0	30.0 / 7.7
4% 410 H	15.0 / 14.0	16.0 / 2.8	4.9 / 11.0	8.7 / 15.0	49.0 / 22.0
6% 410 H	.76 / 1.0	3.6 / 5.2	1.4 / 2.3	4.1 / 7.2	61.0 / 28.0

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	9.0	42.0	54.5	53.5	29.5
	s	7.09	47.84	16.83	41.64	31.01
	cv	78.76	113.91	30.89	77.84	105.12
2% 410 H	$\bar{x}$	37.0	18.0	21.7	43.5	18.9
	s	19.49	3.54	34.29	2.66	19.76
	cv	52.68	19.69	158.38	6.11	104.82
4% 410 H	$\bar{x}$	14.5	9.4	8.0	11.9	35.5
	s	.89	11.70	5.40	5.58	23.92
	cv	6.11	124.42	67.98	47.10	67.39
6% 410 H	$\bar{x}$	.9	4.4	1.9	5.7	44.5
	s	.21	1.42	.80	2.75	29.24
	cv	24.16	32.22	43.10	48.61	65.70

Table D-2 ANOVA Summary, Schweyer Rheometer Apparent Viscosity, G-tube

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	4235.01	1411.67	4.97	3.10	4.94
Tj	4	1564.91	391.22	1.38	2.87	4.43
(CT)ij	12	6182.84	515.23	1.81	2.28	3.23
Error	20	5681.07	284.05			
TOTAL	39	17663.85				

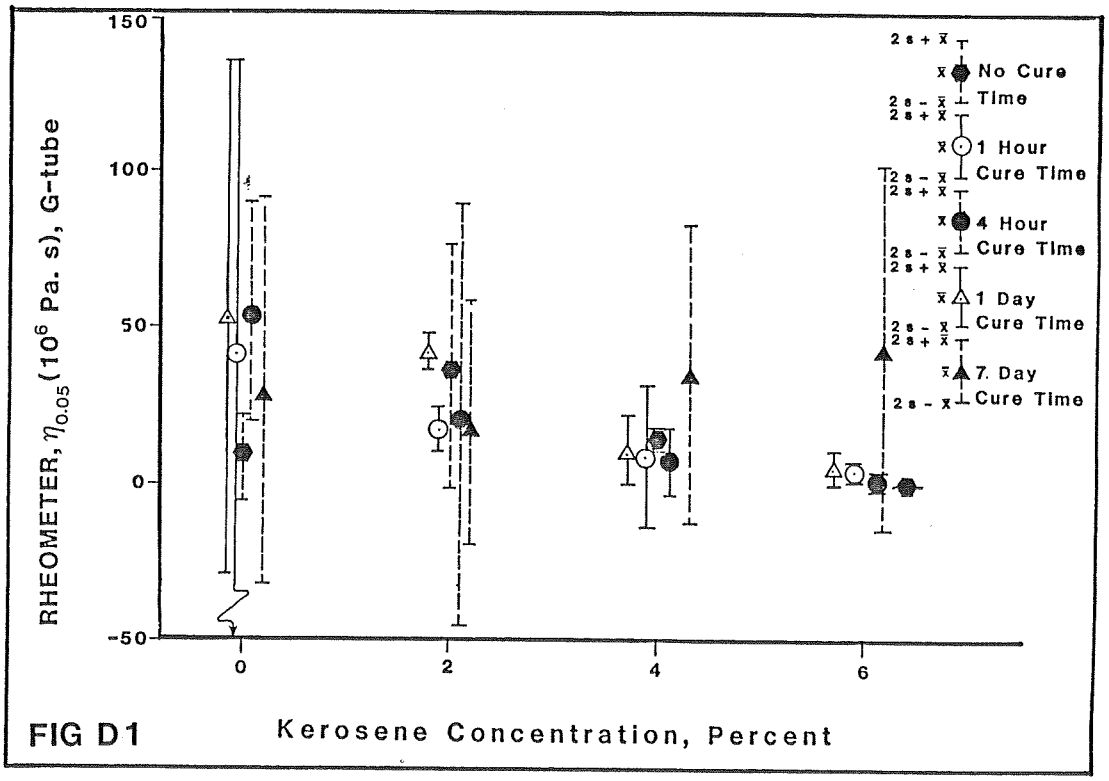

FIG D1

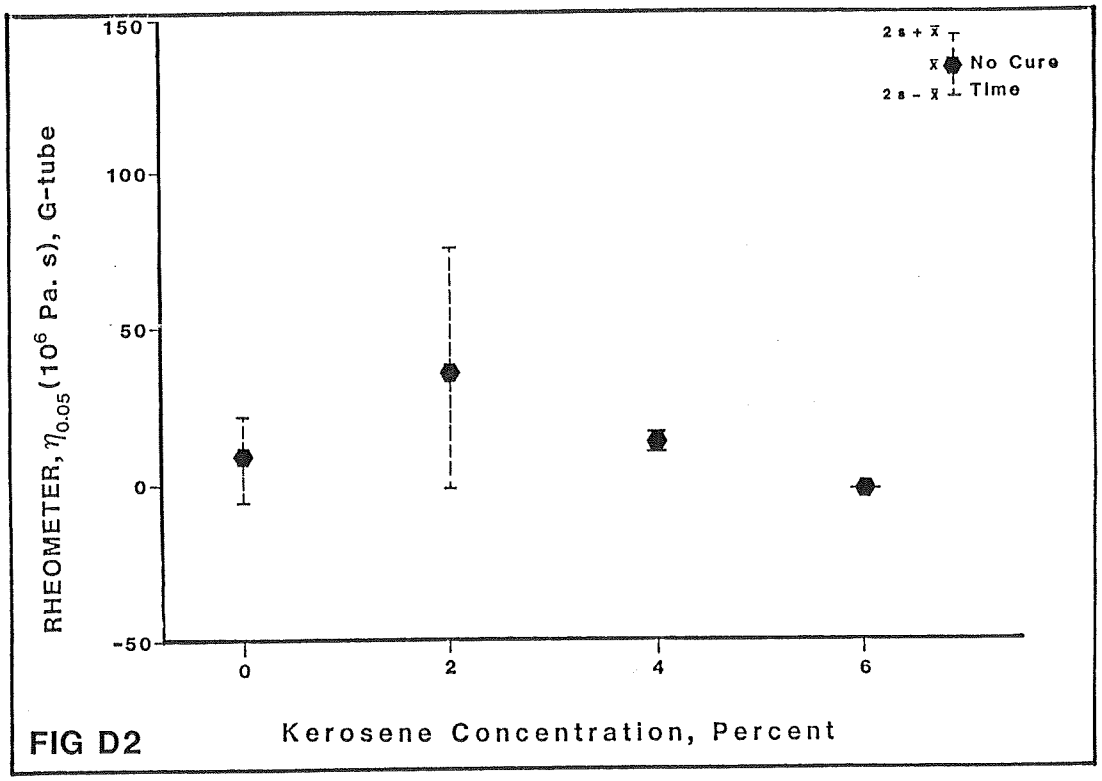
150
100
50
0
-50
RHEOMETER, $\eta_{0.05}$ (10^6 Pa. s), G-tube
0
2
4
6
2 s + x̄
x̄
2 s − x̄
No Cure
Time
Kerosene Concentration, Percent

FIG D2

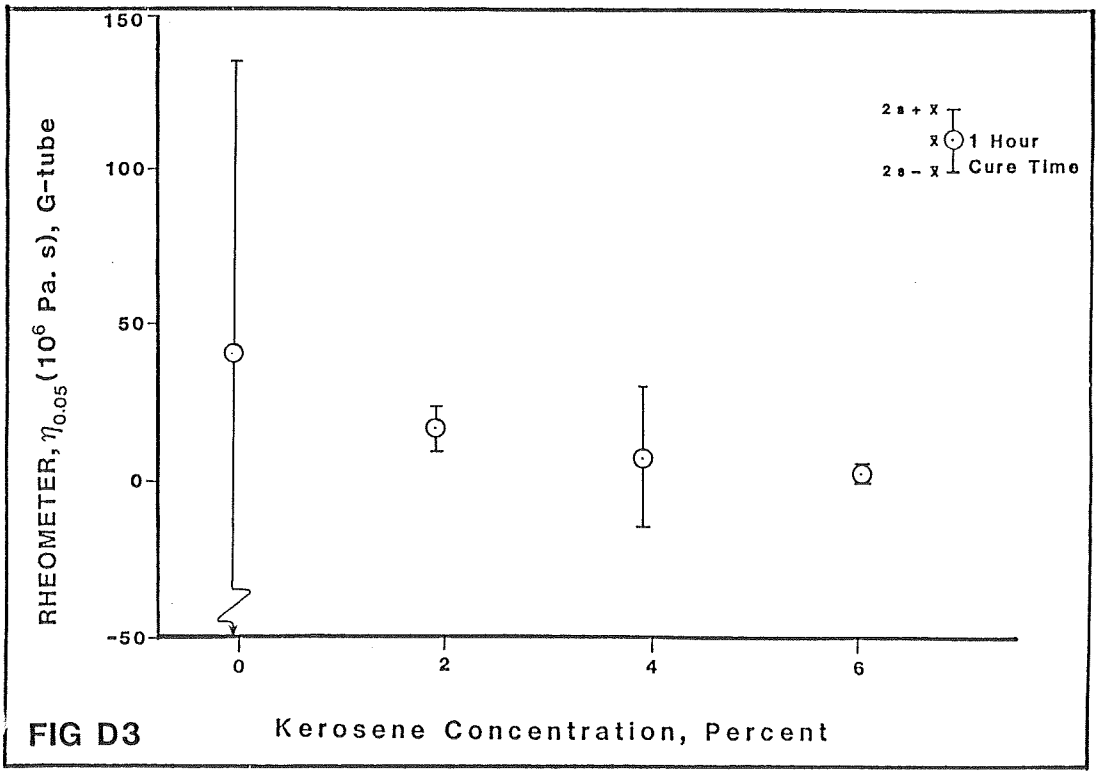
150
100
50
0
-50
RHEOMETER, $\eta_{0.05}$ (10^6 Pa. s), G-tube
0
2
4
6
2 s + x̄
x̄
2 s − x̄
1 Hour
Cure Time
Kerosene Concentration, Percent

FIG D3

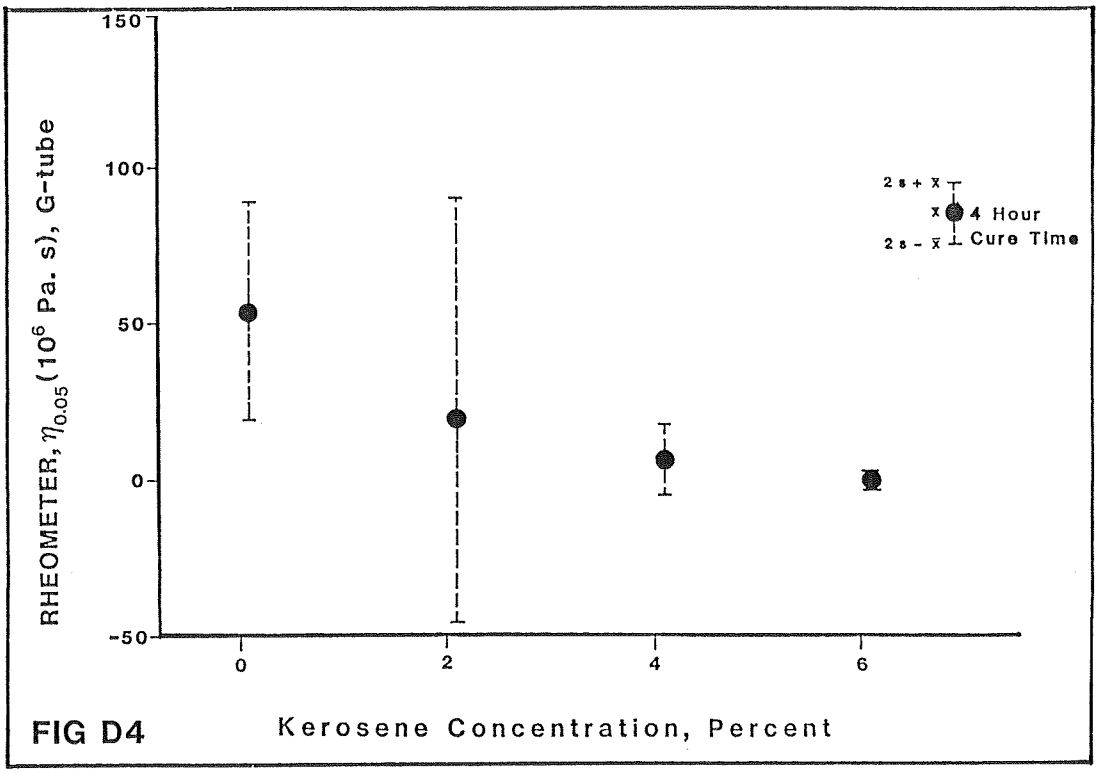
150
100
50
0
-50
RHEOMETER, $\eta_{0.05}$ (10^6 Pa. s), G-tube
0
2
4
6
2 s + x̄
x̄
2 s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG D4

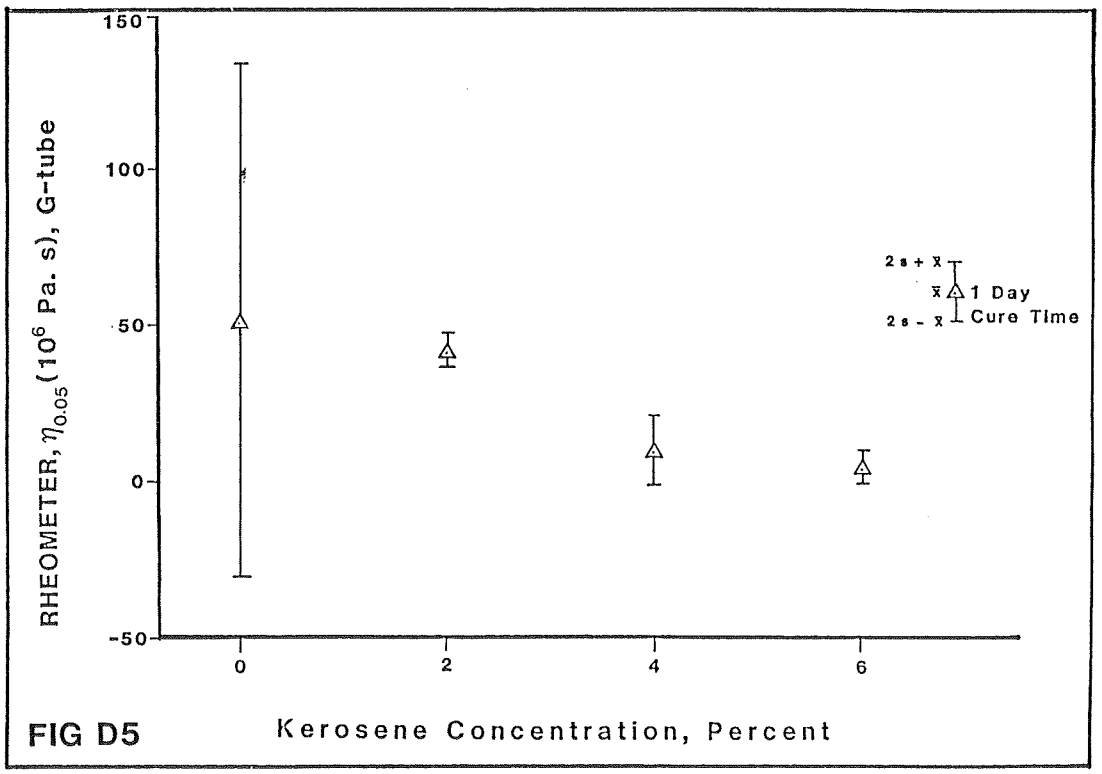
150
100
50
0
-50
RHEOMETER, $\eta_{0.05}$ (10^6 Pa. s), G-tube
0
2
4
6
2 s + x̄
x̄
2 s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG D5

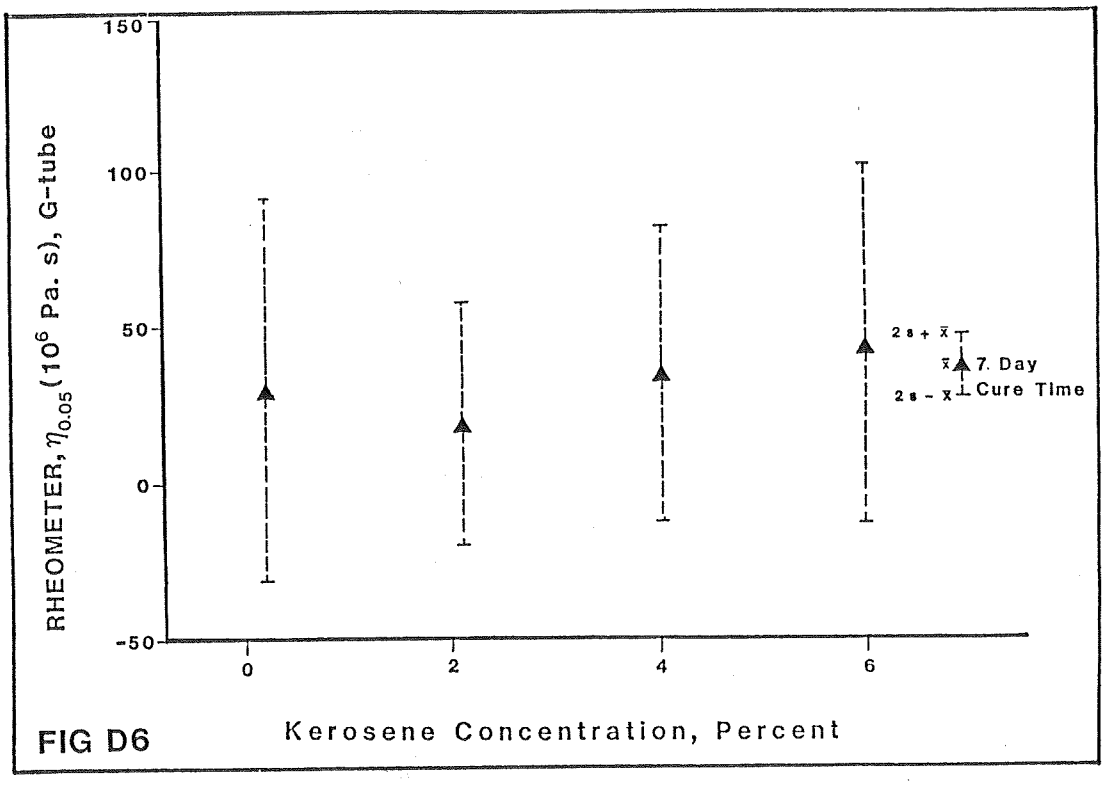
150
100
50
0
-50
RHEOMETER, $\eta_{0.05}$ (10^6 Pa. s), G-tube
0
2
4
6
Kerosene Concentration, Percent
2s + x̄
x̄
2s - x̄
7. Day
Cure Time

FIG D6

APPENDIX E

VISCOSITY ($\eta_{0.05}$) BY SCHWEYER RHEOMETER AT 39.2F (4C), F-TUBE

Table E-1 Schweyer Rheometer, Apparent Viscosity, $\eta_{0.05}$, 10^6Pa-s, F-tube

a. Measured and Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	3.7 / 130	240 / 140	540 / 300	430 / 120	43 / 210
2% 410 H	49 / 110	44 / 41	6.1 / 77	120 / 72	260 / 150
4% 410 H	21 / 21	14 / 29	14 / 24	16 / 18	200 / 68
6% 410 H	2.3 / 9.0	4.5 / 3.4	2.9 / 4.1	14 / 13	280 / 88

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	66.85	190.00	420.00	275.00	126.50
	s	111.902	88.60	212.640	274.660	147.962
	cv	167.39	46.63	50.63	99.88	116.97
2% 410 H	$\bar{x}$	79.50	42.50	41.55	96.00	205.00
	s	54.046	2.658	62.817	42.528	97.460
	cv	67.98	6.25	151.19	44.30	47.54
4% 410 H	$\bar{x}$	21.00	21.50	19.00	17.00	134.00
	s	0	13.290	8.860	1.772	116.952
	cv	0	61.81	46.63	10.42	87.28
6% 410 H	$\bar{x}$	5.65	3.95	3.50	13.50	184.00
	s	5.936	.975	1.063	.886	170.112
	cv	105.07	24.67	30.38	6.56	92.45

Table E-2 ANOVA Summary, Schweyer Rheometer Apparent Viscosity, F-tube

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	233823.53	77941.17	12.36	3.10	4.94
Tj	4	44453.05	11113.26	1.76	2.87	4.43
(CT)ij	12	168774.11	14064.50	2.23	2.28	3.23
Error	20	126051.52	6302.57			
TOTAL	39	573102.22				

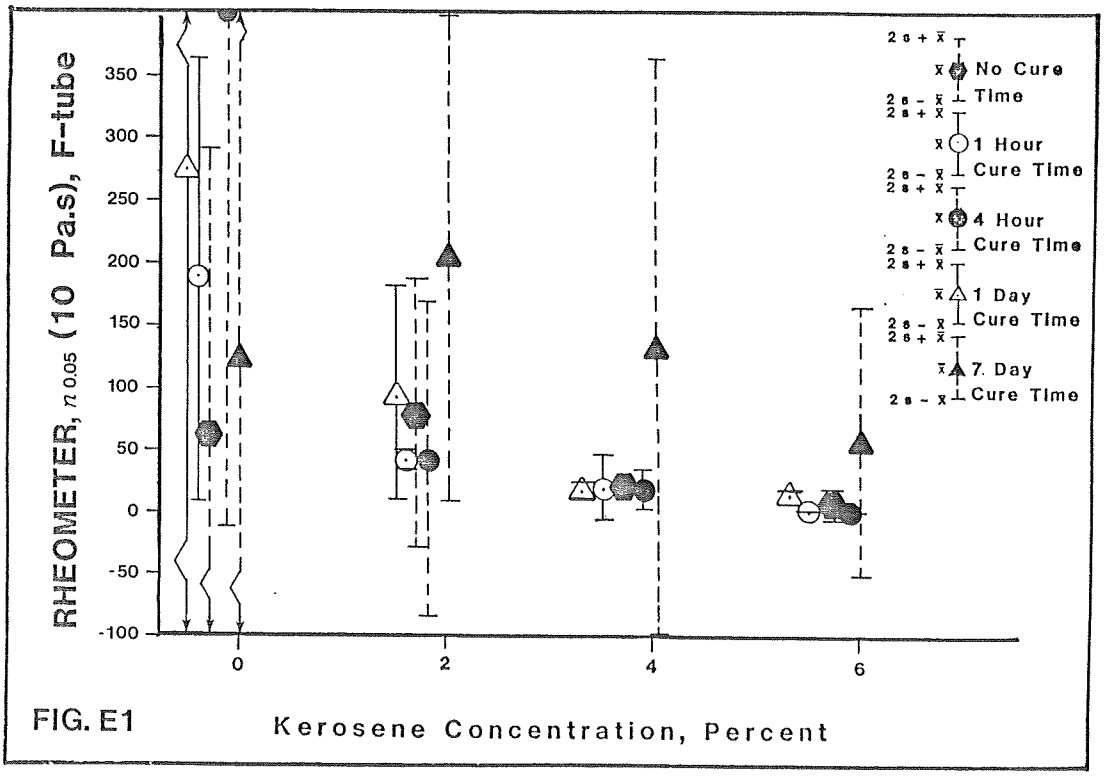

FIG. E1

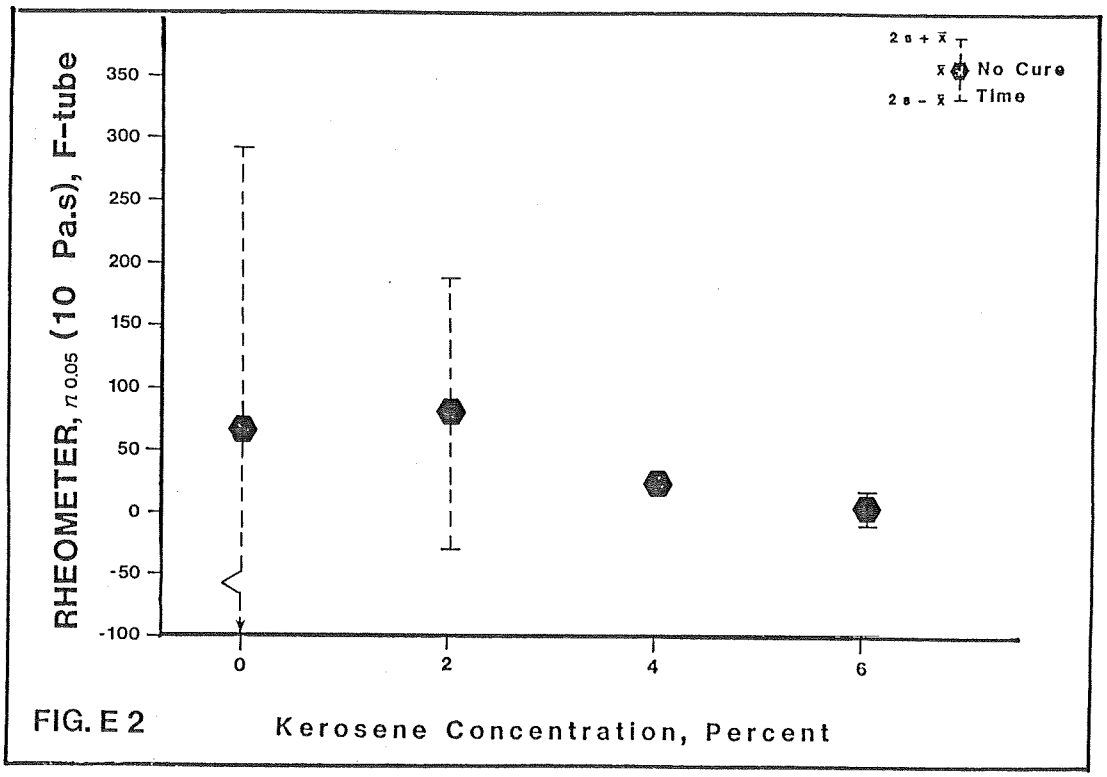
RHEOMETER, $\eta_{0.05}$ (10 Pa.s), F-tube
350
300
250
200
150
100
50
0
-50
-100
0
2
4
6
2 s + x̄
x̄
2 s - x̄
No Cure
Time
Kerosene Concentration, Percent

FIG. E 2

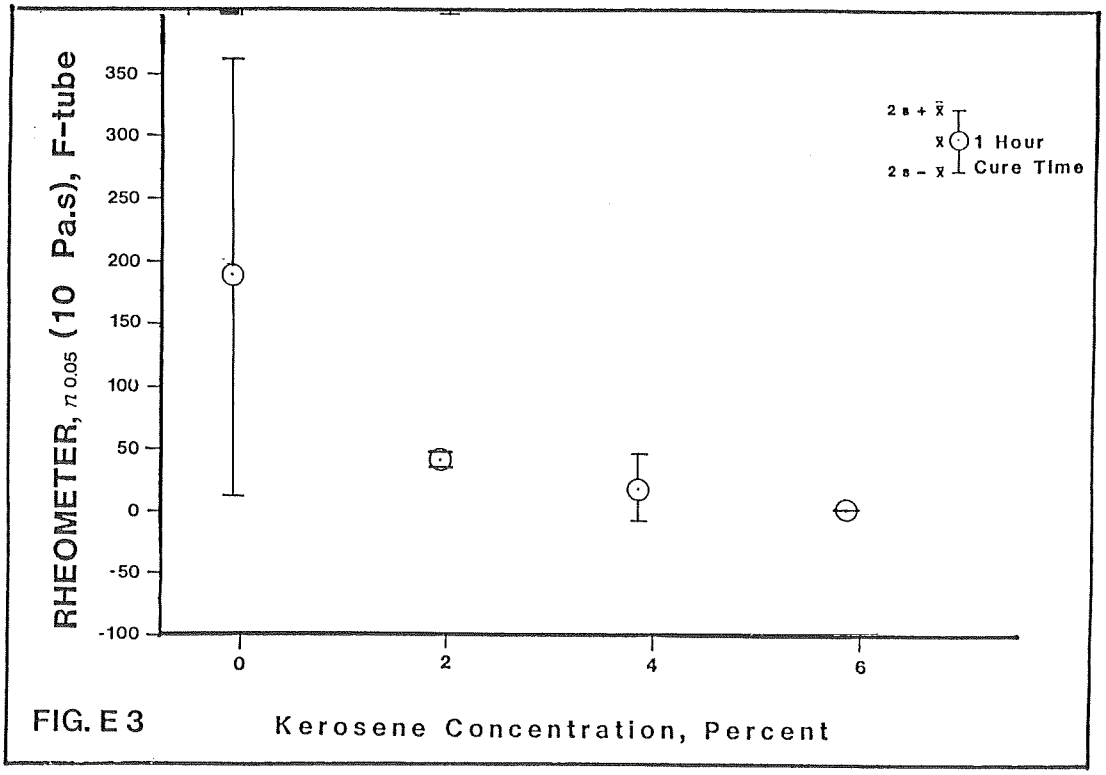
RHEOMETER, $\eta_{0.05}$ (10 Pa.s), F-tube
350
300
250
200
150
100
50
0
-50
-100
0
2
4
6
2 s + x̄
x̄
2 s - x̄
1 Hour
Cure Time
Kerosene Concentration, Percent

FIG. E 3

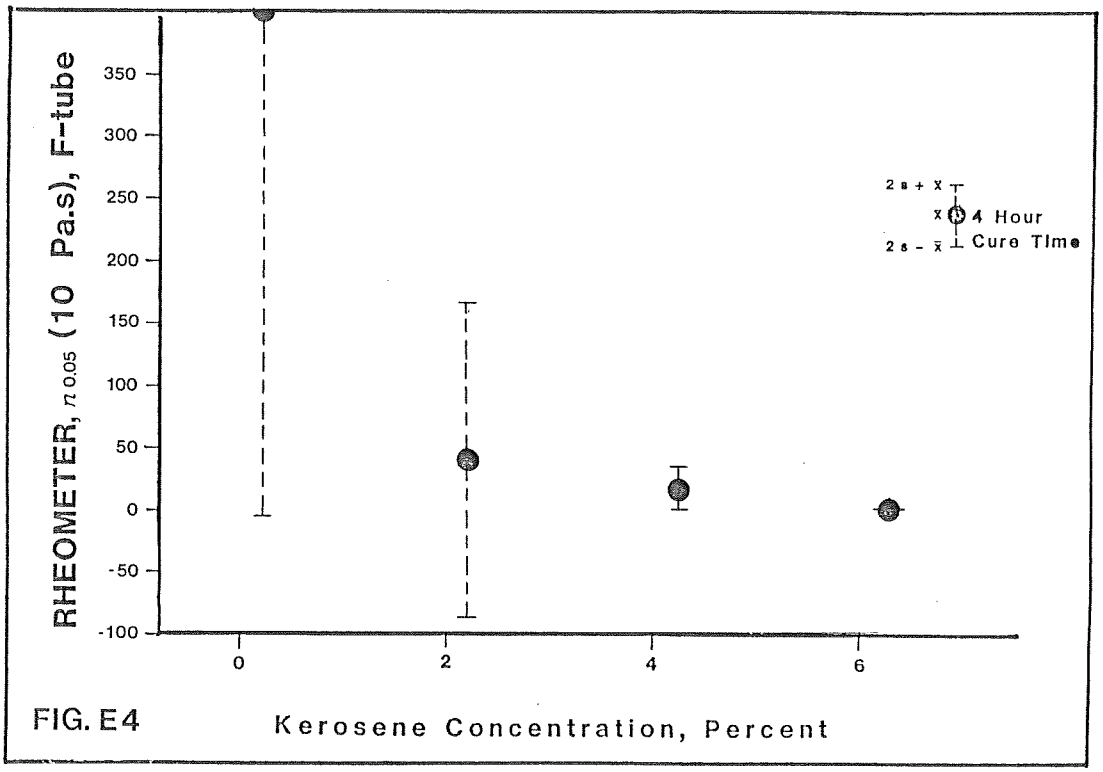
RHEOMETER, η 0.05 (10 Pa.s), F-tube
350
300
250
200
150
100
50
0
-50
-100
0
2
4
6
2 s + x̄
x̄
2 s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG. E4

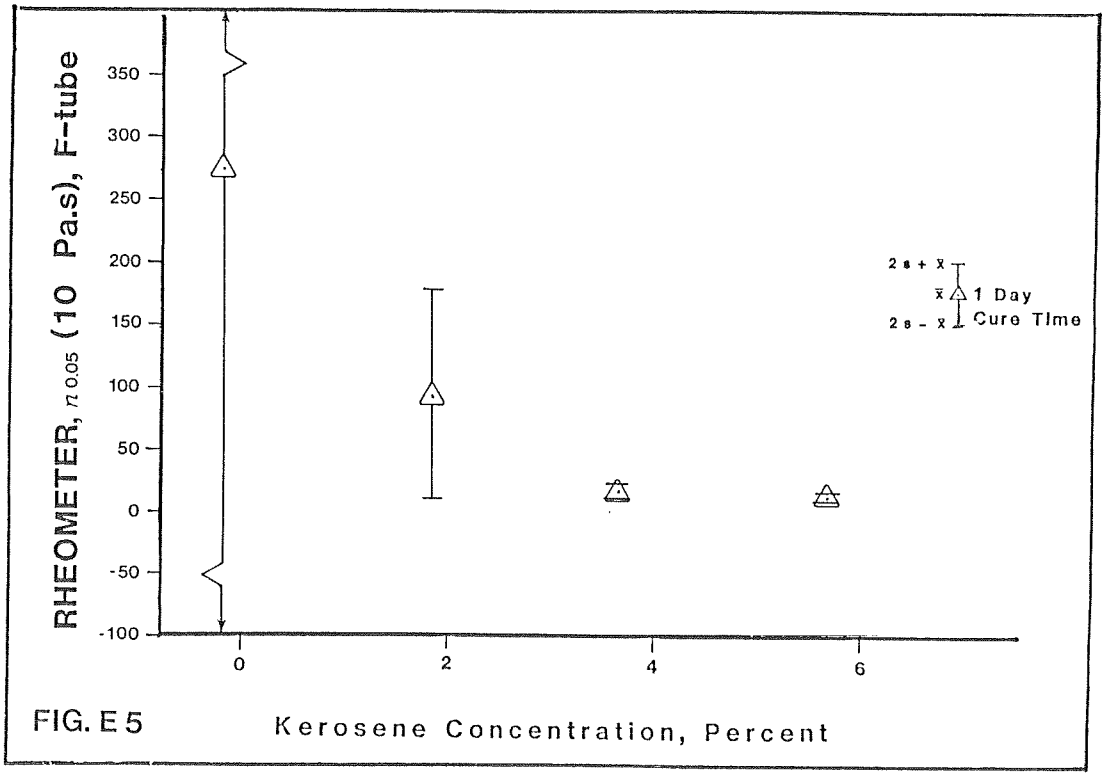
RHEOMETER, η 0.05 (10 Pa.s), F-tube
350
300
250
200
150
100
50
0
-50
-100
0
2
4
6
2 s + x̄
x̄
2 s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG. E5

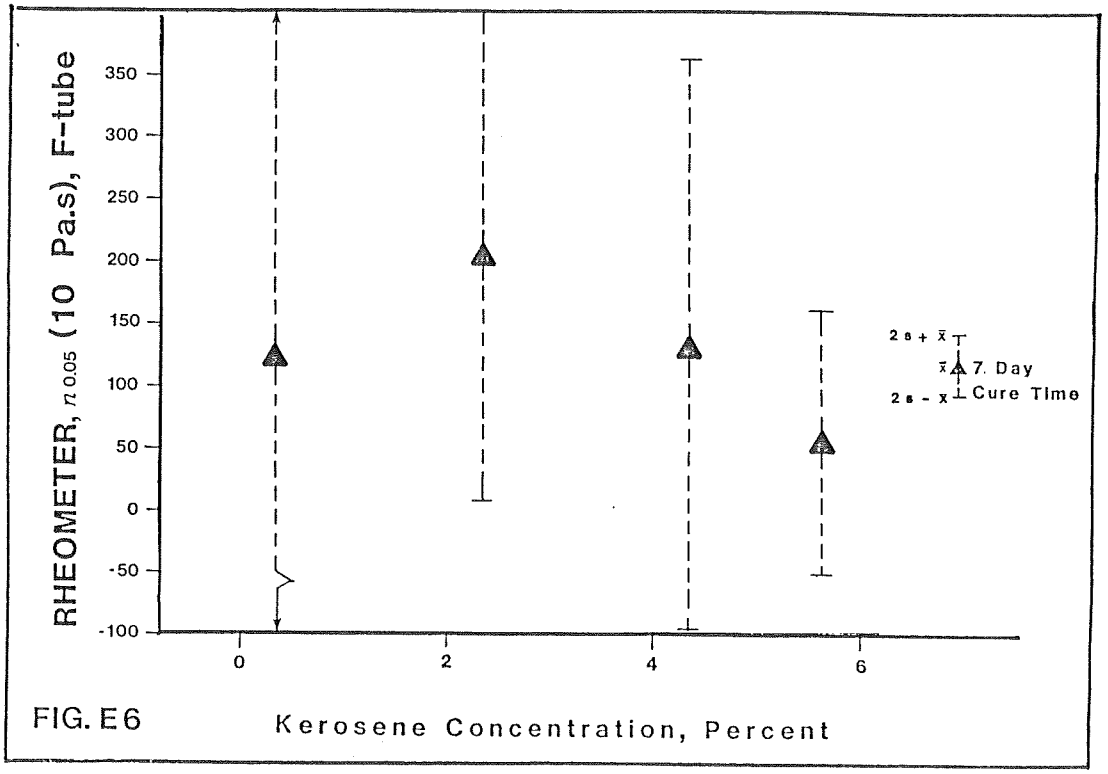
RHEOMETER, η 0.05 (10 Pa.s), F-tube
350
300
250
200
150
100
50
0
-50
-100
0
2
4
6
2 s + x̄
x̄ 7. Day
2 s - x̄ Cure Time
Kerosene Concentration, Percent

FIG. E6

APPENDIX F

FORCE-DUCTILITY LOAD AT FAILURE AT 39.2F (4C)

Table F-1 Load at Failure, Pounds

a. Measured Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	18.07	19.41	19.60	20.16	23.01
	21.32	20.78	21.37	17.39	22.69
	20.86	23.69	21.10	20.49	20.59
	27.42	12.69	20.70	17.50	23.87
	28.15	20.59	20.08	18.47	27.05
	26.46	16.02	19.32	21.35	23.90
2% 410 H	8.98	9.49	9.65	18.09	15.99
	8.14	9.94	9.70	13.98	16.16
	9.00	9.70	9.24	16.99	17.15
	8.84	8.33	9.41	14.19	19.36
	6.88	9.76	10.64	11.72	19.46
	7.31	11.32	11.39	14.78	18.71
4% 410 H	4.83	7.87	5.88	5.10	12.90
	5.40	5.67	6.64	4.64	12.90
	7.07	6.77	6.64	4.59	13.19
	3.79	4.00	6.13	7.26	15.70
	4.22	5.45	5.53	6.66	18.12
	3.79	4.54	6.91	7.47	14.09
6% 410 H	5.26	2.28	4.54	8.04	11.50
	4.54	3.38	2.52	7.95	14.11
	4.46	3.73	3.41	5.53	14.33
	2.60	2.82	2.44	3.73	10.32
	3.27	2.49	1.74	3.81	14.01
	3.62	2.89	1.90	4.83	12.96

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	23.71	18.86	20.36	19.23	23.52
	s	4.164	3.910	.827	1.668	2.110
	cv	17.56	20.73	4.06	8.67	8.97
2% 410 H	$\bar{x}$	8.19	9.76	10.01	14.96	17.81
	s	.916	.958	.834	2.280	1.57
	cv	11.18	9.82	8.34	15.25	8.85
4% 410 H	$\bar{x}$	4.85	5.72	6.29	5.95	14.48
	s	1.255	1.425	.529	1.328	2.076
	cv	25.88	24.92	8.42	22.31	14.33
6% 410 H	$\bar{x}$	3.96	2.93	2.76	5.65	12.87
	s	.971	.543	1.052	1.937	1.634
	cv	24.54	18.51	38.13	34.29	12.70

Table F-2 Load at Failure, Pounds

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	20.08	21.29	20.69	19.35	22.10
	27.34	16.43	20.03	19.11	24.94
2% 410 H	8.71	9.71	9.53	16.35	16.43
	7.68	9.80	10.48	13.56	19.18
4% 410 H	5.77	6.77	6.39	4.78	13.00
	3.93	4.66	6.19	7.13	15.97
6% 410 H	4.75	3.13	3.49	7.17	13.31
	3.16	2.73	2.05	4.12	12.43

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	23.71	18.86	20.36	19.23	23.52
	s	6.432	4.306	.582	.213	2.519
	cv	27.13	22.83	2.86	1.11	10.71
2% 410 H	$\bar{x}$	8.20	9.76	10.01	14.96	17.81
	s	9.13	8.240	.842	2.472	2.431
	cv	11.14	84.43	8.41	16.53	13.65
4% 410 H	$\bar{x}$	4.85	5.71	6.29	5.95	14.48
	s	1.62	1.86	.175	2.084	2.634
	cv	33.50	32.66	2.78	35.02	18.19
6% 410 H	$\bar{x}$	3.958	2.932	2.76	5.65	12.87
	s	1.409	.352	1.300	2.702	.782
	cv	35.59	12.00	46.99	47.85	6.08

Table F-3 ANOVA Summary, Load at Failure

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	1439.94	479.98	137.82	3.10	4.94
Tj	4	330.63	82.66	23.73	2.87	4.43
(CT)ij	12	111.72	9.31	2.67	2.28	3.23
Error	20	69.66	3.48			
TOTAL	39	1951.93				

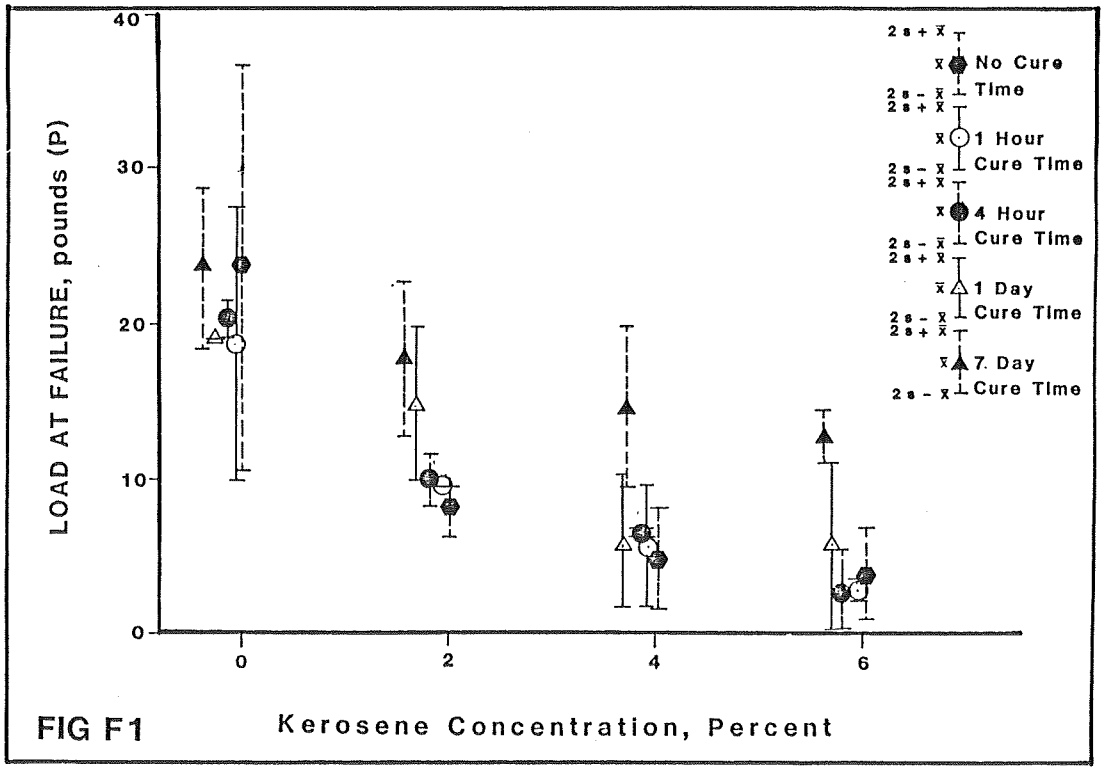

FIG F1

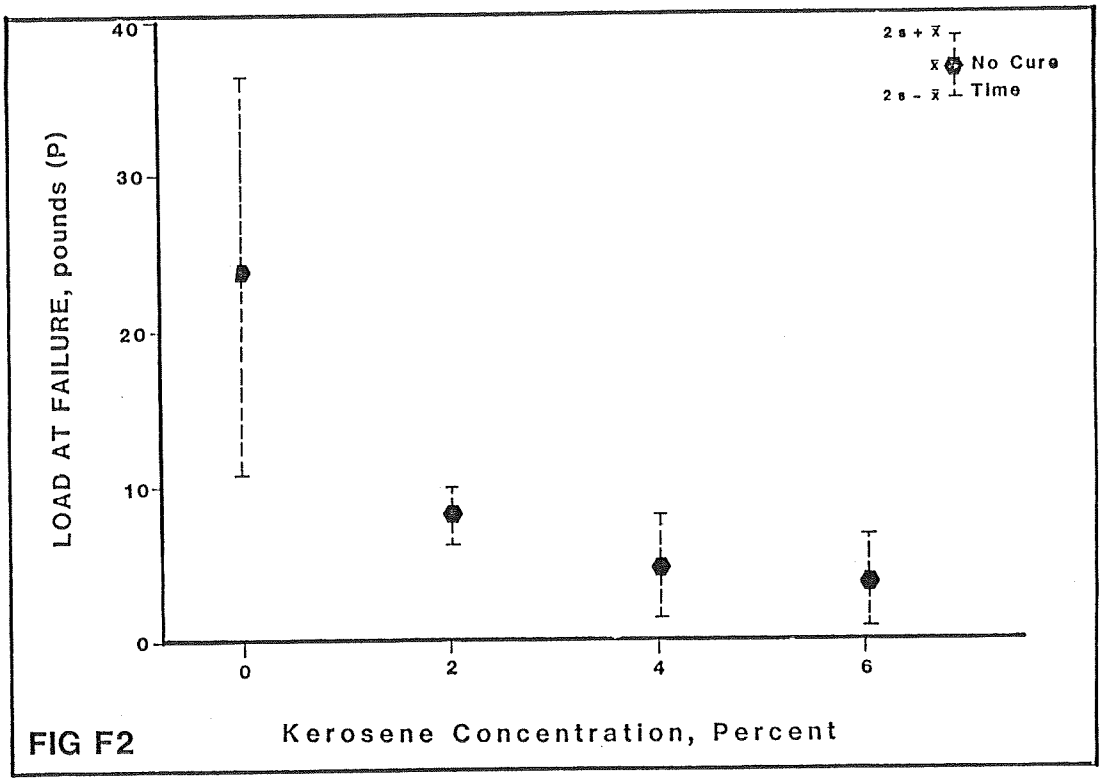
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
2
4
6
2 s + x̄
x̄
2 s − x̄
No Cure
Time
Kerosene Concentration, Percent

FIG F2

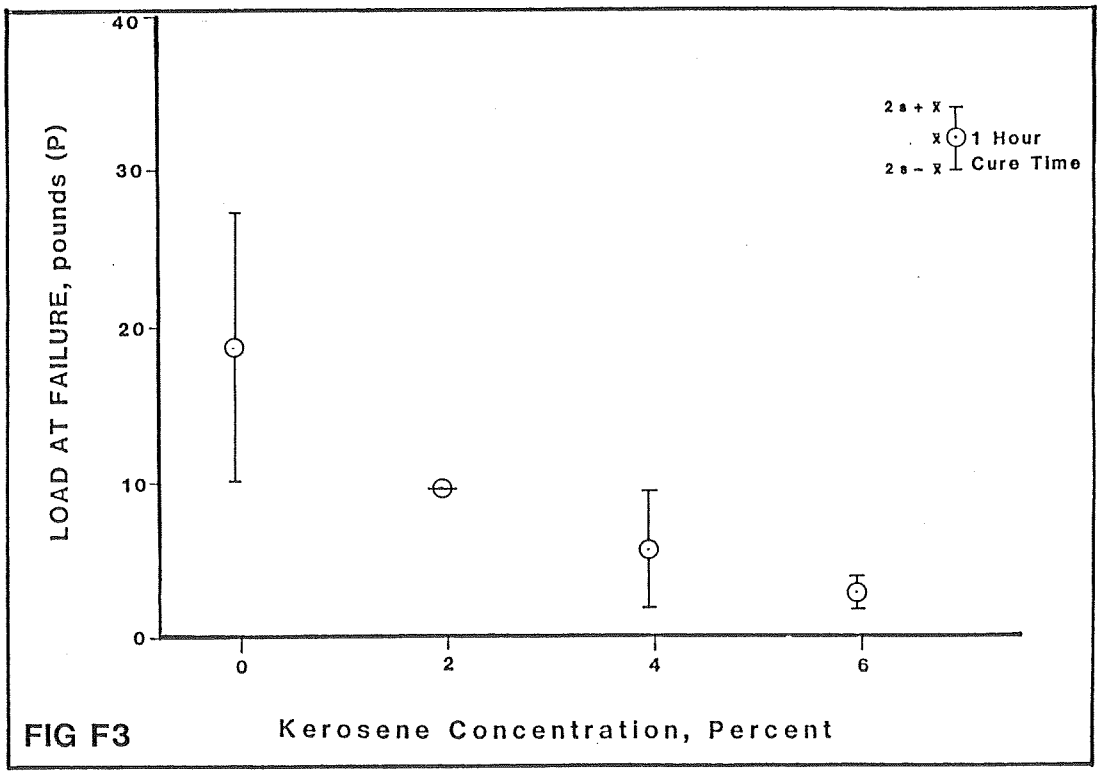
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
2
4
6
2 s + x̄
x̄
2 s − x̄
1 Hour
Cure Time
Kerosene Concentration, Percent

FIG F3

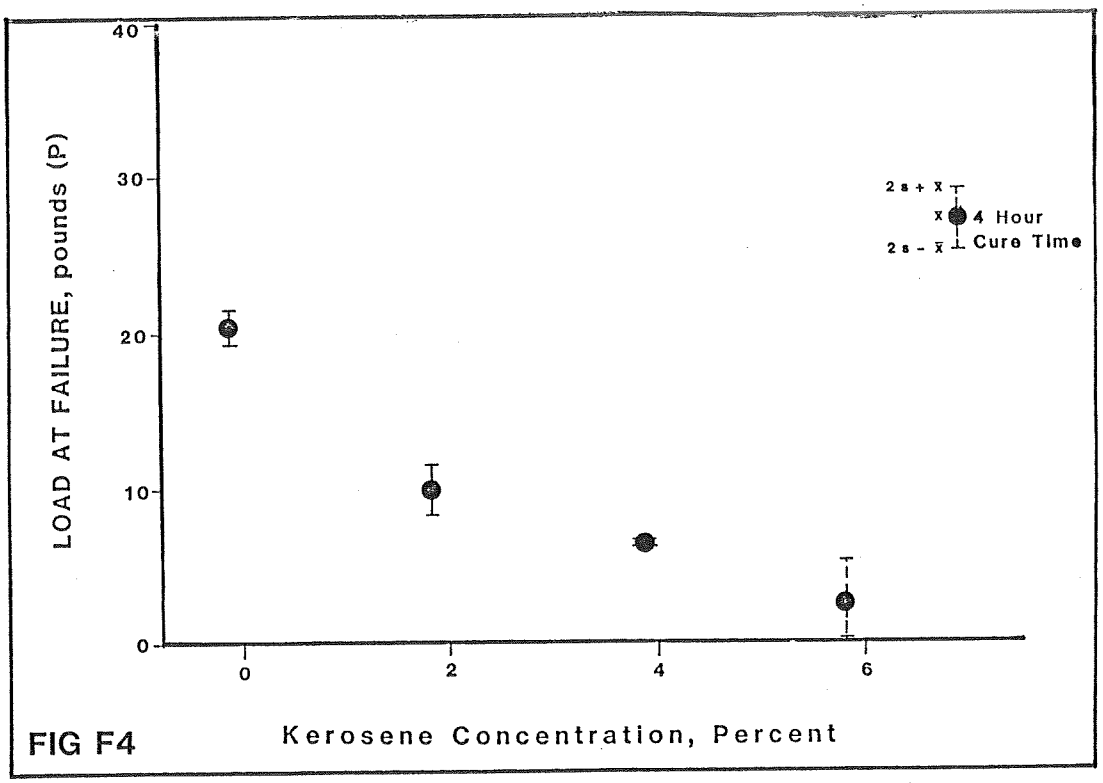
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
2
4
6
2s + x̄
x̄
2s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG F4

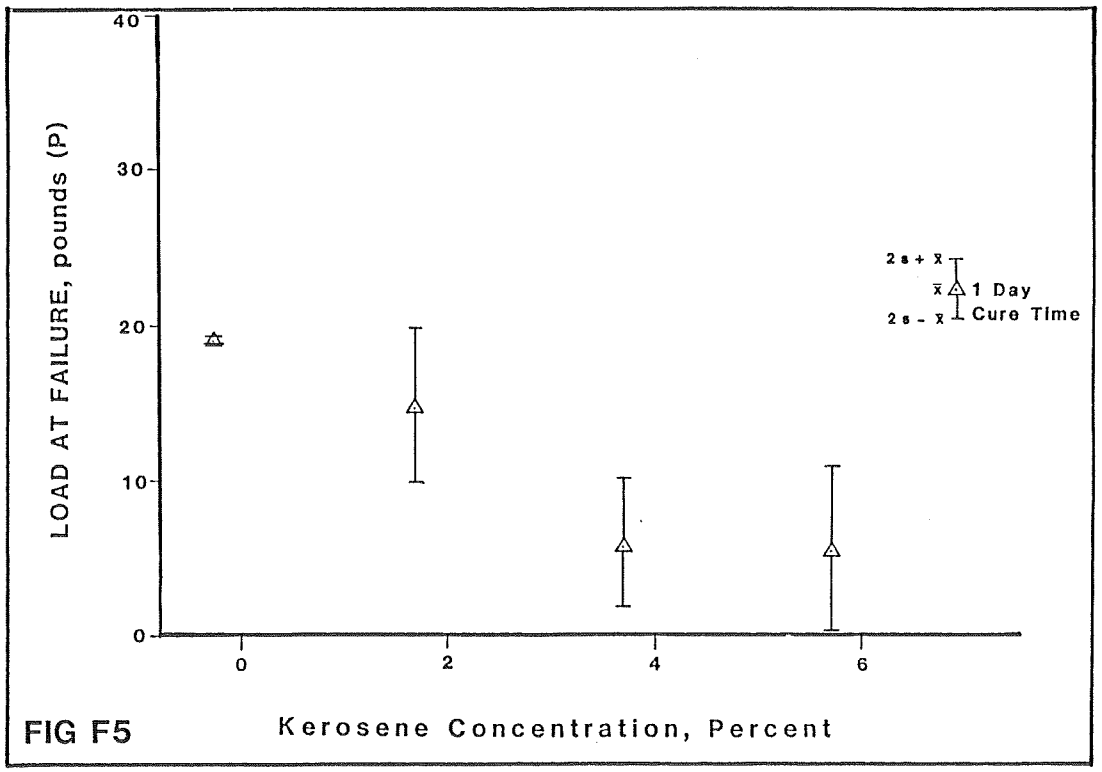
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
2
4
6
2s + x̄
x̄
2s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG F5

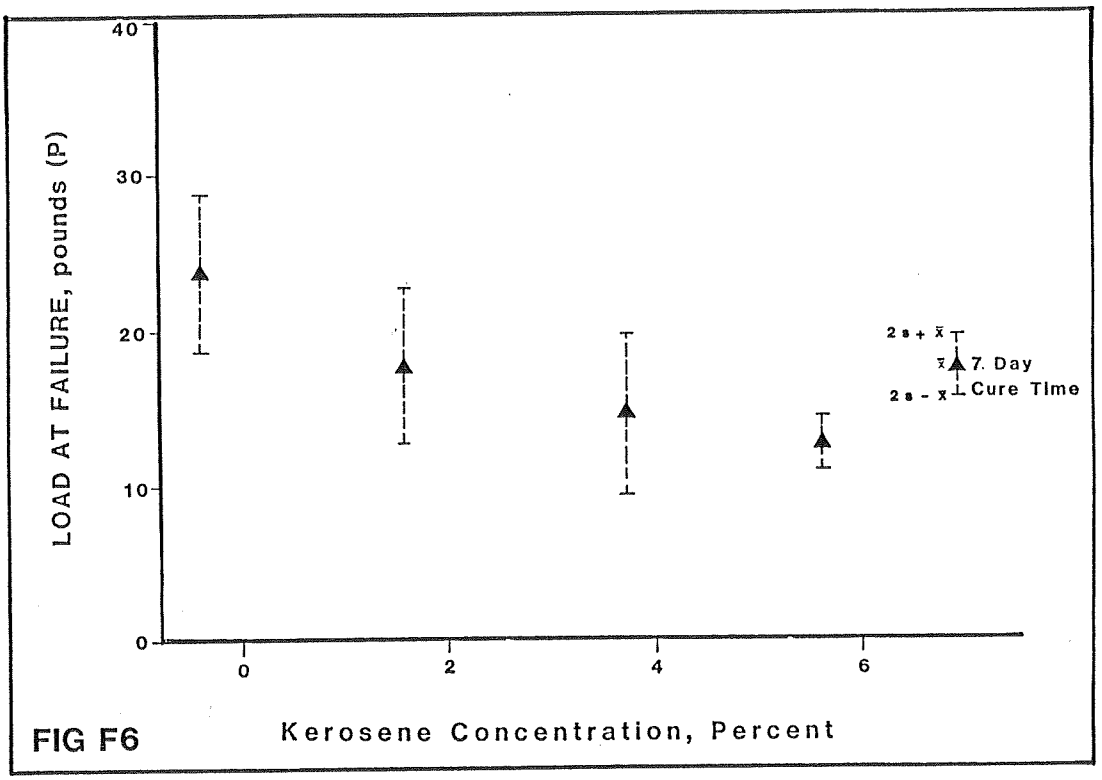
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
2
4
6
2s + x̄
x̄
2s - x̄
7. Day
Cure Time
Kerosene Concentration, Percent

FIG F6

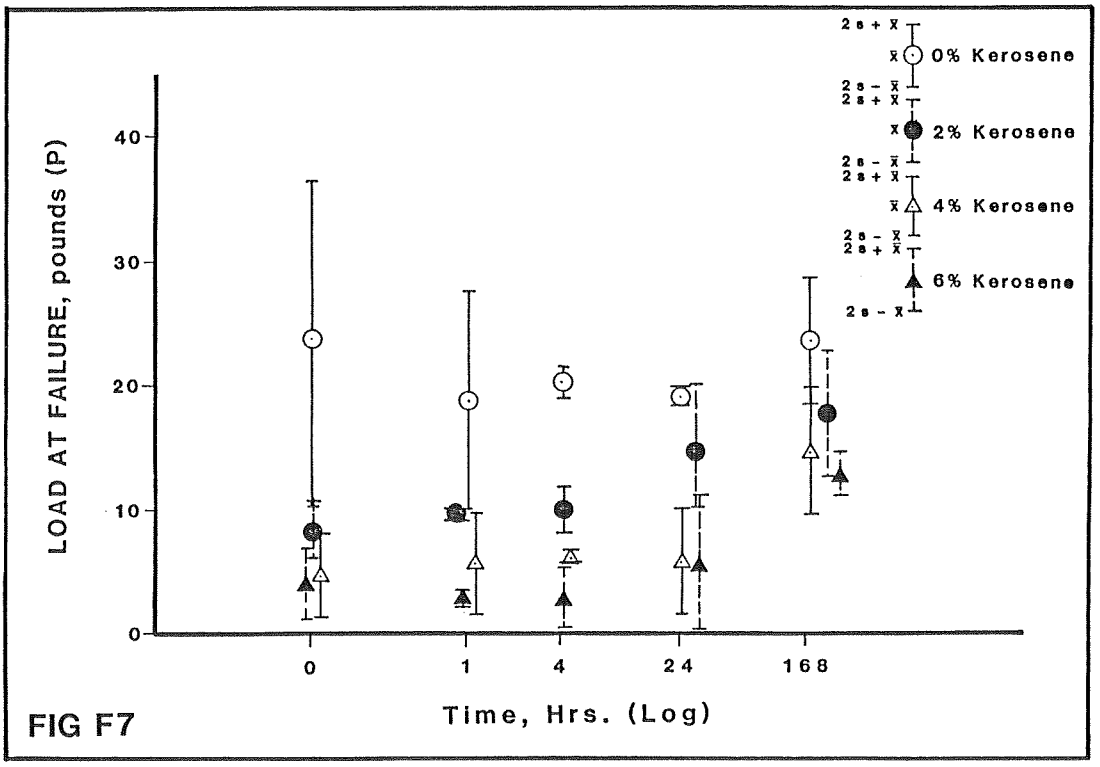
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
1
4
24
168
2s + x̄
x̄
2s - x̄
0% Kerosene
2% Kerosene
4% Kerosene
6% Kerosene
Time, Hrs. (Log)

FIG F7

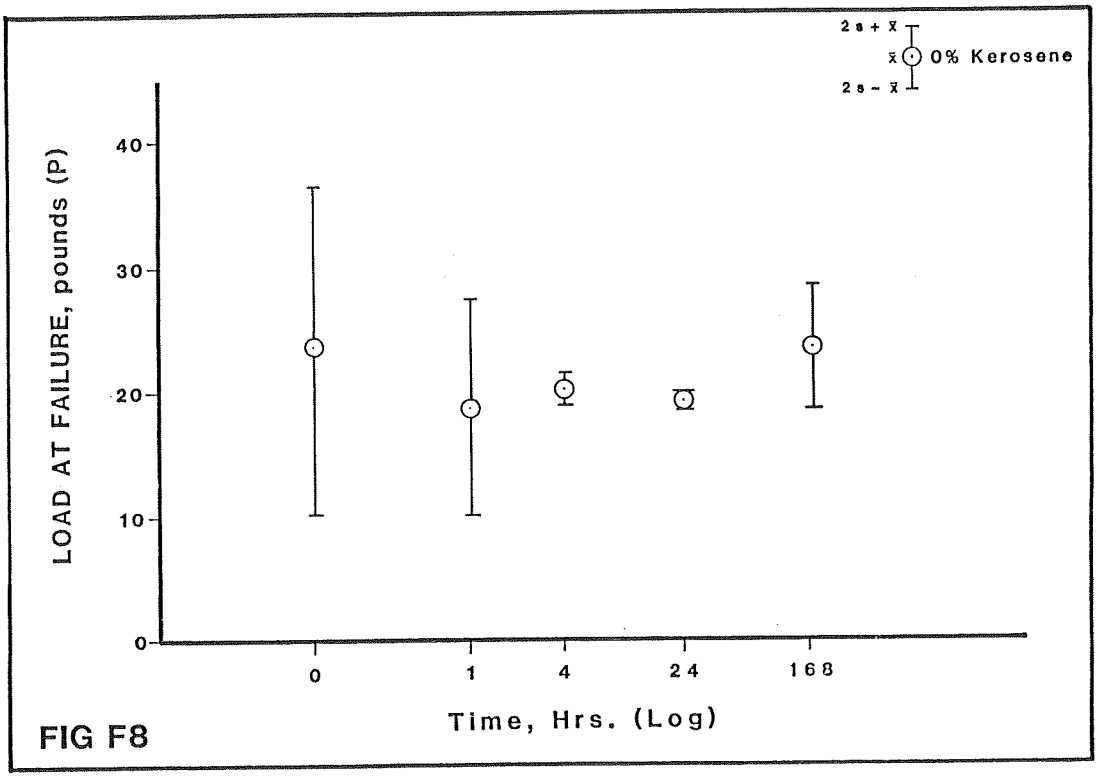
2s + x̄
x̄
2s - x̄
0% Kerosene
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
1
4
24
168
Time, Hrs. (Log)

FIG F8

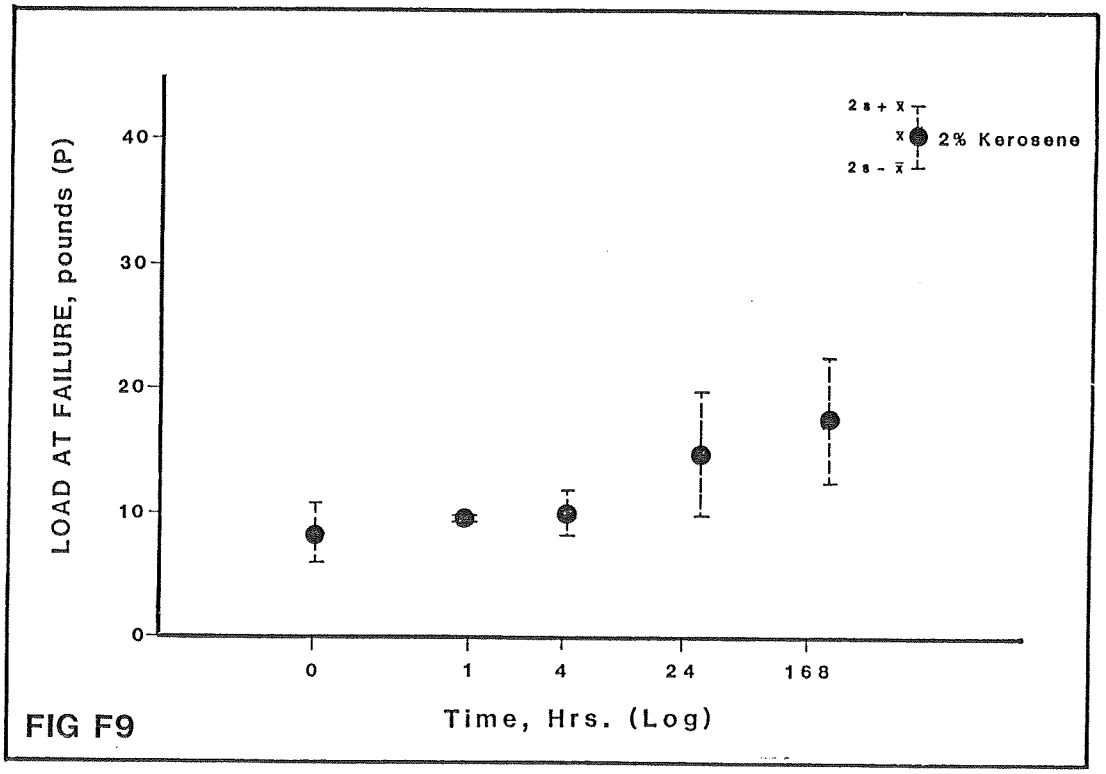
2s + x̄
x̄
2s - x̄
2% Kerosene
LOAD AT FAILURE, pounds (P)
40
30
20
10
0
0
1
4
24
168
Time, Hrs. (Log)

FIG F9

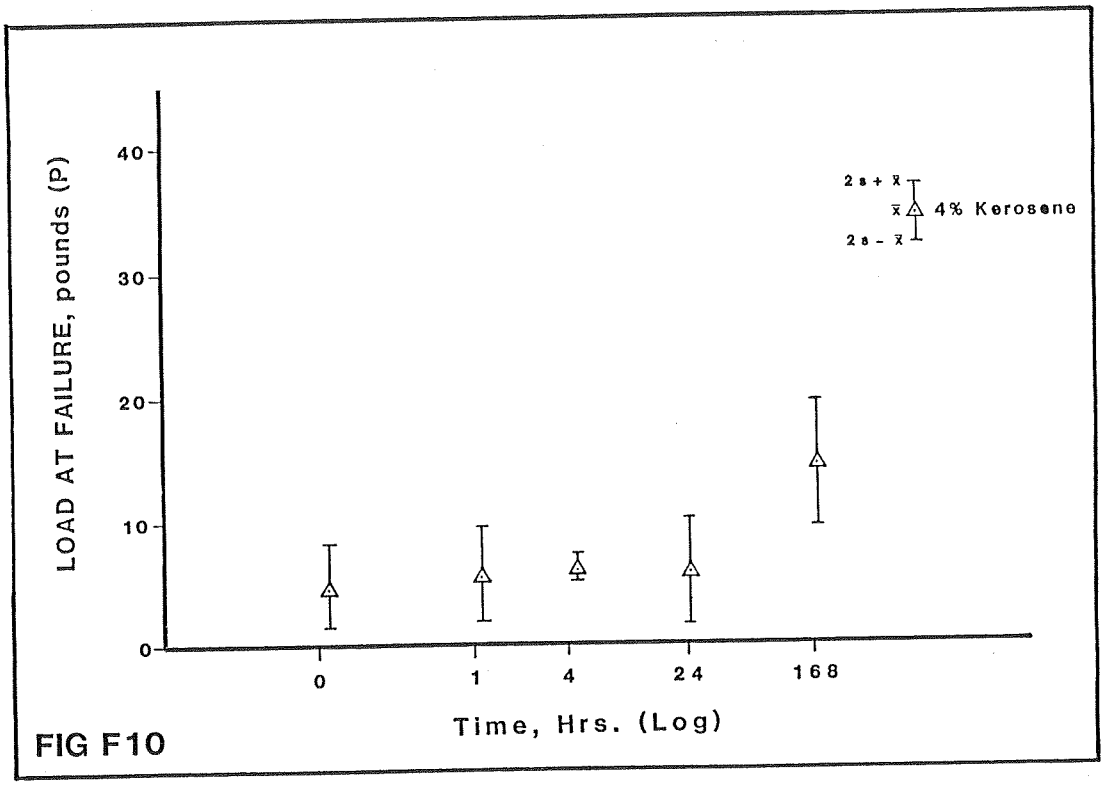

FIG F10

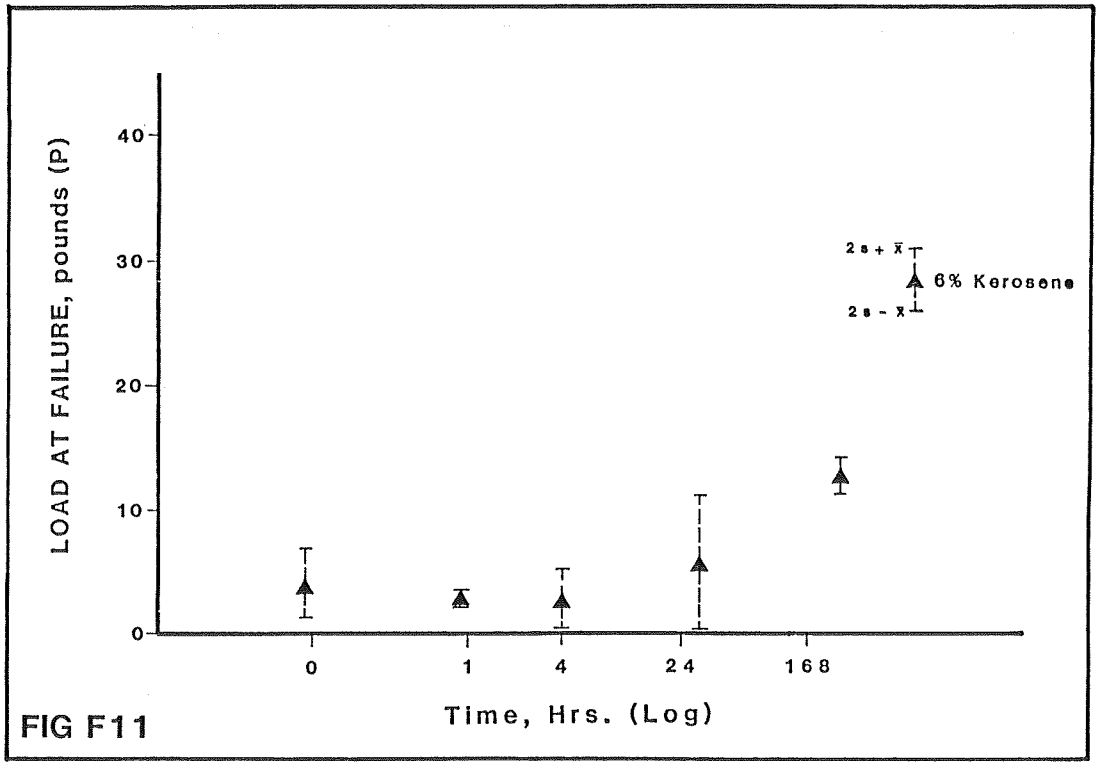

FIG F11

APPENDIX G

FORCE DUCTILITY ELONGATION AT FAILURE AT 39.2F(4C)

Table G-1 Elongation at Failure, mm

a. Measured Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	130	184	193	202	183
	173	216	219	160	171
	141	190	174	181	166
	174	112	169	263	166
	152	154	170	142	175
	174	115	164	184	164
2% 410 H	151	170	172	197	151
	142	119	143	182	160
	152	146	204	217	177
	239	223	186	68	152
	201	211	204	179	156
	196	205	217	184	137
4% 410 H	126	154	145	222	183
	113	165	136	189	171
	252	163	171	209	174
	149	171	175	166	159
	179	191	175	168	181
	166	123	213	168	187
6% 410 H	169	226	164	108	180
	235	154	169	156	162
	186	278	171	220	190
	186	185	118	197	216
	236	155	157	205	194
	208	115	84	198	182

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	157.3	161.8	181.5	188.7	170.8
	s	19.20	42.32	20.93	41.91	7.19
	cv	12.20	26.15	11.53	22.22	4.21
2% 410 H	$\bar{x}$	180.2	179.0	187.7	171.2	155.5
	s	38.07	41.00	26.97	52.45	13.1
	cv	21.13	22.91	14.37	30.64	8.42
4% 410 H	$\bar{x}$	164.2	161.2	169.2	187.0	175.8
	s	49.48	22.42	27.12	23.98	10.1
	cv	30.14	13.91	16.03	12.83	5.76
6% 410 H	$\bar{x}$	203.3	185.5	143.8	180.7	187.3
	s	27.83	58.46	35.21	41.46	17.9
	cv	13.68	31.52	24.48	22.95	9.54

Table G-2 Elongation at Failure, mm

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	148.0	196.7	195.3	181.0	173.3
	166.7	127.0	167.3	196.3	168.3
2% 410 H	148.3	145.0	173.0	198.7	162.7
	212.0	213.0	202.3	143.7	148.3
4% 410 H	163.7	160.7	150.7	206.7	176.0
	164.7	161.7	187.7	167.3	175.7
6% 410 H	196.7	219.3	168.0	161.3	177.3
	210.0	151.7	119.7	200.0	197.3

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	157.4	161.9	181.5	188.7	170.8
	s	16.57	61.75	24.45	13.56	4.43
	cv	10.53	38.16	13.47	7.19	2.59
2% 410 H	$\bar{x}$	180.2	179.0	187.7	171.2	155.5
	s	56.44	60.25	25.96	48.73	12.76
	cv	31.33	33.66	13.83	28.46	8.20
4% 410 H	$\bar{x}$	164.2	161.2	169.2	187.0	175.9
	s	.89	.89	32.78	34.91	.27
	cv	.54	.55	19.37	18.67	.15
6% 410 H	$\bar{x}$	203.4	185.5	142.4	180.7	187.3
	s	11.78	59.89	45.45	34.29	17.72
	cv	5.79	32.29	31.93	18.98	9.46

Table G-3 ANOVA Summary, Elongation at Failure, mm

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	213.65	71.26	.12	3.10	4.94
Tj	4	351.07	87.77	.15	2.87	4.43
(CT)ij	12	10699.92	891.66	1.54	2.28	3.23
Error	20	11594.95	579.75			
TOTAL	39	22859.58				

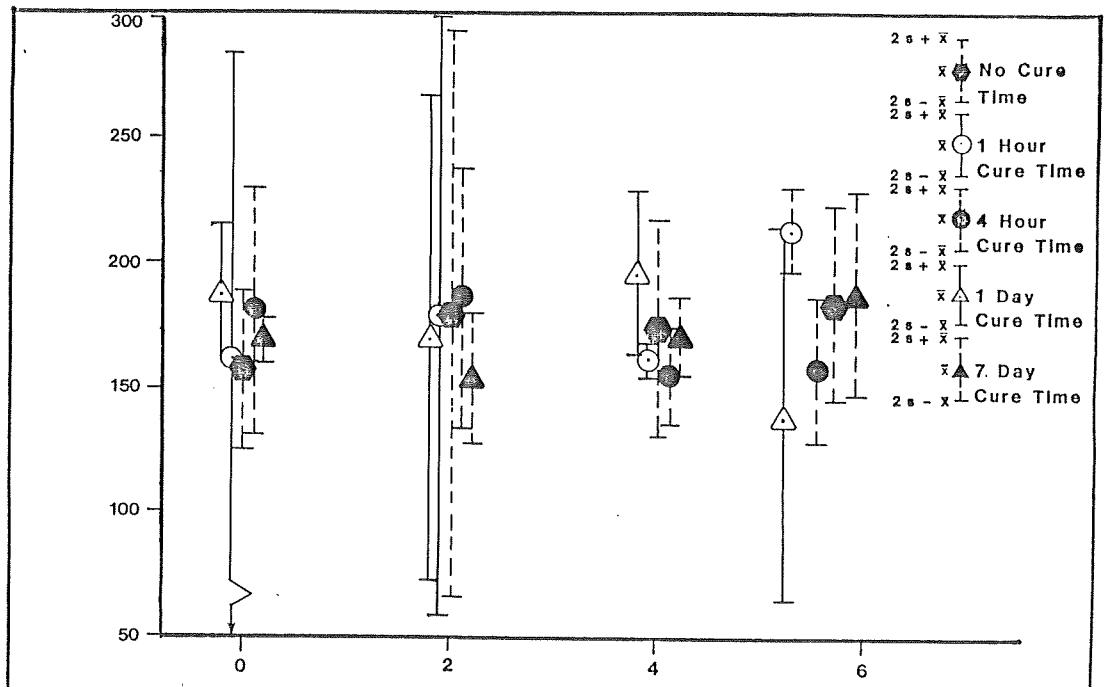

FIG. G1 Kerosene Concentration, Percent

APPENDIX H

FORCE-DUCTILITY ENGINEERING

STRESS AT FAILURE AT 39.2F (4C)

Table H-1 Engineering Stress at Failure, psi

a. Calculated Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	112.9 133.2 130.4	121.3 129.9 148.0	122.5 133.6 131.9	126.0 108.7 128.0	143.8 141.8 128.7
	171.4 175.9 165.3	79.3 128.7 100.1	123.8 125.5 129.4	109.4 115.4 133.4	149.2 169.0 149.4
2% 410 H	50.9 56.3 56.1	59.3 62.1 60.6	60.3 60.6 57.8	113.1 87.4 106.2	100.0 101.0 107.2
	55.3 43.0 45.7	52.1 61.0 70.7	58.8 66.5 71.2	88.7 73.2 92.4	121.0 121.6 116.9
4% 410 H	33.7 44.2 30.2	49.2 35.4 42.3	36.8 41.5 41.5	28.7 31.9 29.0	80.6 80.6 82.5
	23.7 26.3 23.7	25.0 34.1 28.4	38.3 34.6 43.2	45.3 41.6 46.7	98.1 113.2 88.0
6% 410 H	32.9 28.4 27.9	14.2 21.1 23.3	28.4 15.8 21.3	34.6 50.2 49.7	71.9 88.2 89.5
	16.3 20.5 22.7	17.6 15.6 18.1	15.3 10.9 11.9	23.3 23.8 30.2	64.5 87.5 81.0

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	148.18	117.88	127.78	120.15	146.98
	s	26.023	24.434	4.525	10.398	13.166
	cv	17.56	20.73	3.54	8.66	8.96
2% 410 H	$\bar{x}$	51.22	60.97	62.53	93.50	111.28
	s	5.734	5.959	5.214	14.276	9.820
	cv	11.20	9.77	8.34	15.27	8.82
4% 410 H	$\bar{x}$	30.30	35.73	39.32	37.20	90.50
	s	7.847	8.902	3.293	8.280	12.956
	cv	25.90	24.91	8.38	22.26	14.32
6% 410 H	$\bar{x}$	24.78	18.32	17.27	35.30	80.43
	s	6.055	3.390	6.566	12.101	10.193
	cv	24.43	18.51	38.03	34.28	12.67

Table H-2 Engineering Stress at Failure, psi

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	125.50 / 170.87	133.06 / 102.70	129.33 / 126.23	120.90 / 119.40	138.10 / 155.87
2% 410 H	54.43 / 48.00	60.67 / 61.27	59.57 / 65.50	102.23 / 84.77	102.73 / 119.83
4% 410 H	36.03 / 24.57	42.30 / 29.17	39.93 / 38.70	29.87 / 44.53	81.23 / 99.77
6% 410 H	29.73 / 19.83	19.53 / 17.10	21.83 / 12.70	44.83 / 25.77	83.20 / 77.67

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	148.18	117.89	127.78	120.15	146.99
	s	40.198	26.907	2.747	1.329	15.744
	cv	27.13	22.83	2.15	1.11	10.71
2% 410 H	$\bar{x}$	51.22	60.97	62.54	93.50	111.28
	s	5.697	.532	5.254	15.470	15.151
	cv	11.12	.87	8.40	16.55	13.61
4% 410 H	$\bar{x}$	30.30	35.74	39.32	37.20	90.50
	s	10.154	11.633	1.090	12.989	16.426
	cv	33.51	32.55	2.77	34.92	18.15
6% 410 H	$\bar{x}$	24.78	18.32	17.27	35.30	80.44
	s	8.711	2.153	8.089	16.887	4.900
	cv	35.40	11.76	46.85	47.84	6.09

Table H-3 ANOVA Summary, Engineering Stress at Failure

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	56354.56	18784.85	138.44	3.10	4.94
Tj	4	12885.49	3221.37	23.74	2.87	4.43
(CT)ij	12	4374.69	364.56	2.69	2.28	3.23
Error	20	2713.78	135.69			
TOTAL	39	76328.52				

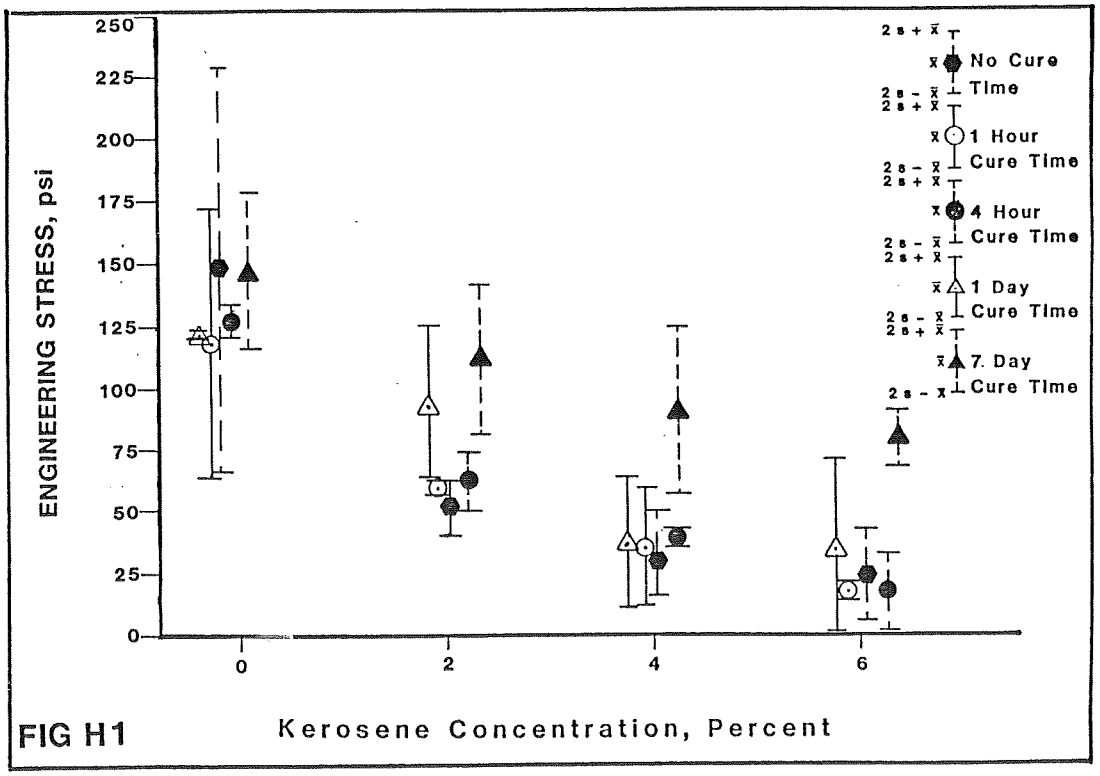

FIG H1

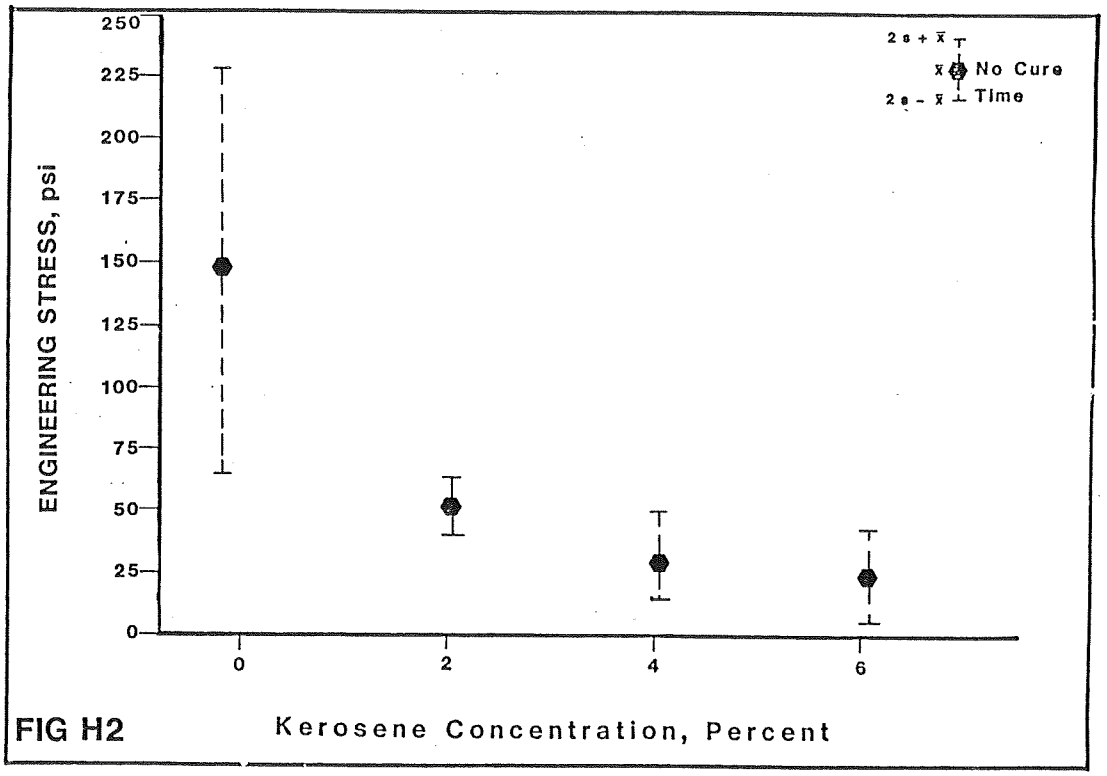
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
2
4
6
2 s + x̄
x̄
2 s - x̄
No Cure
Time
Kerosene Concentration, Percent

FIG H2

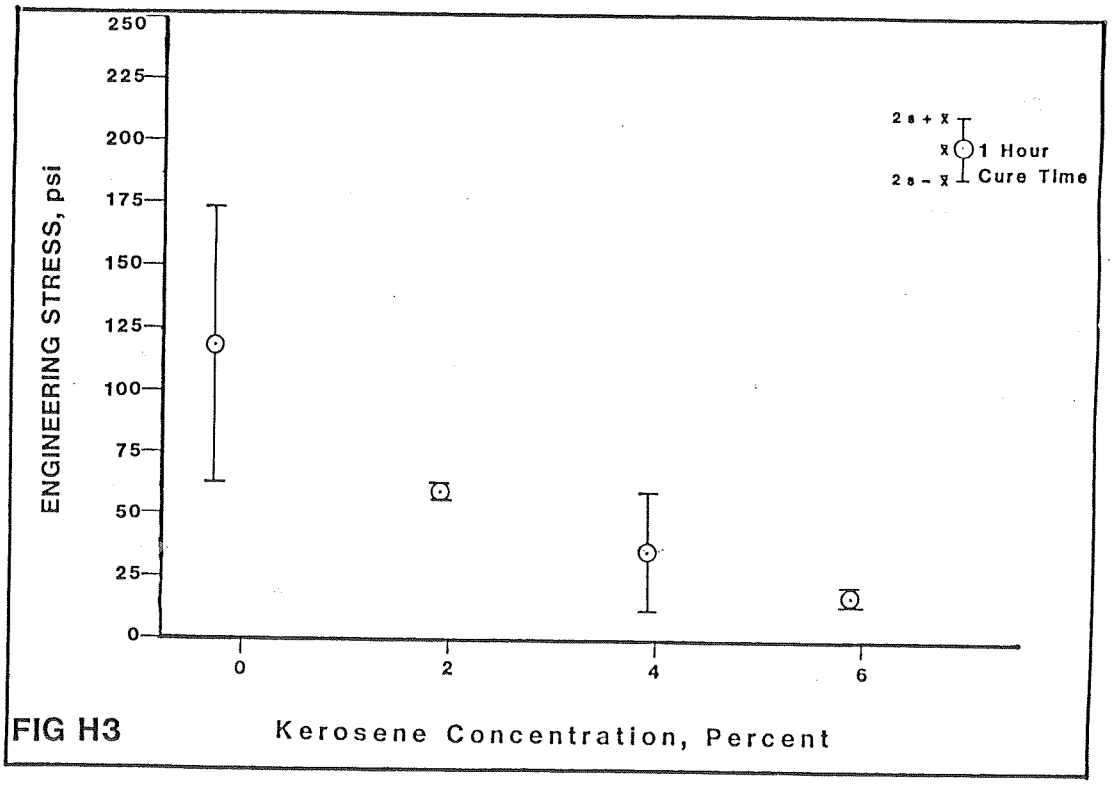
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
2
4
6
2 s + x̄
x̄
2 s - x̄
1 Hour
Cure Time
Kerosene Concentration, Percent

FIG H3

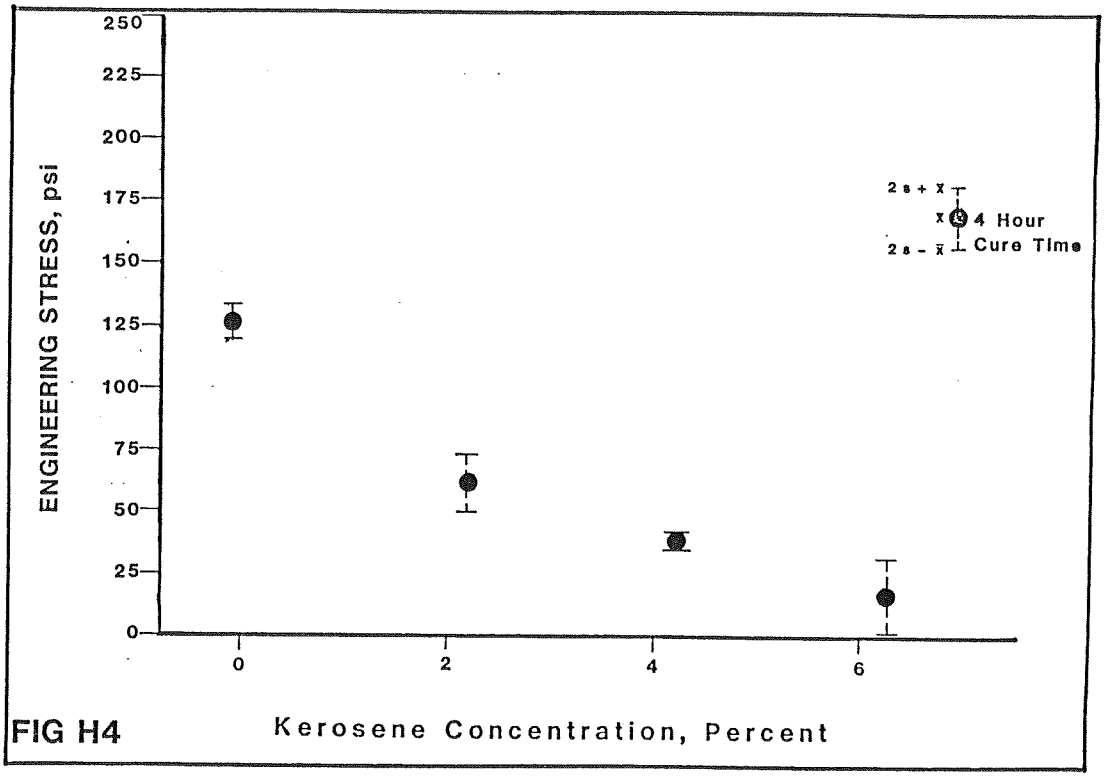
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
2
4
6
2s + x̄
x̄
2s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG H4

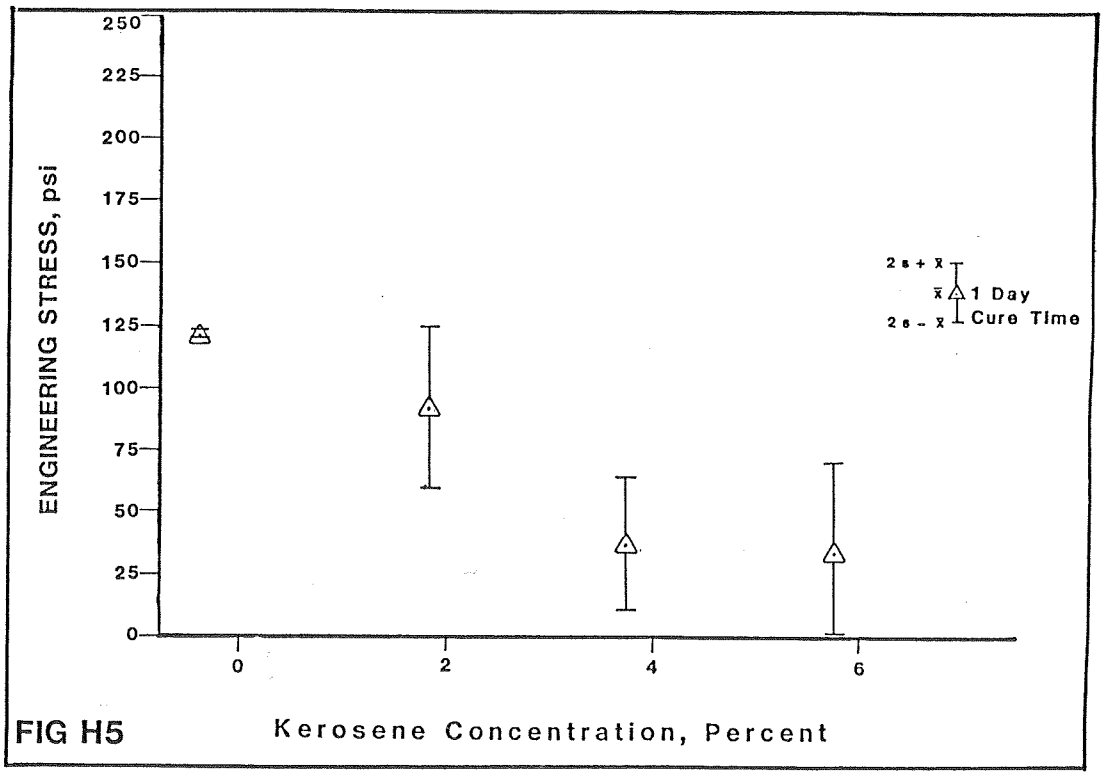
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
2
4
6
2s + x̄
x̄
2s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG H5

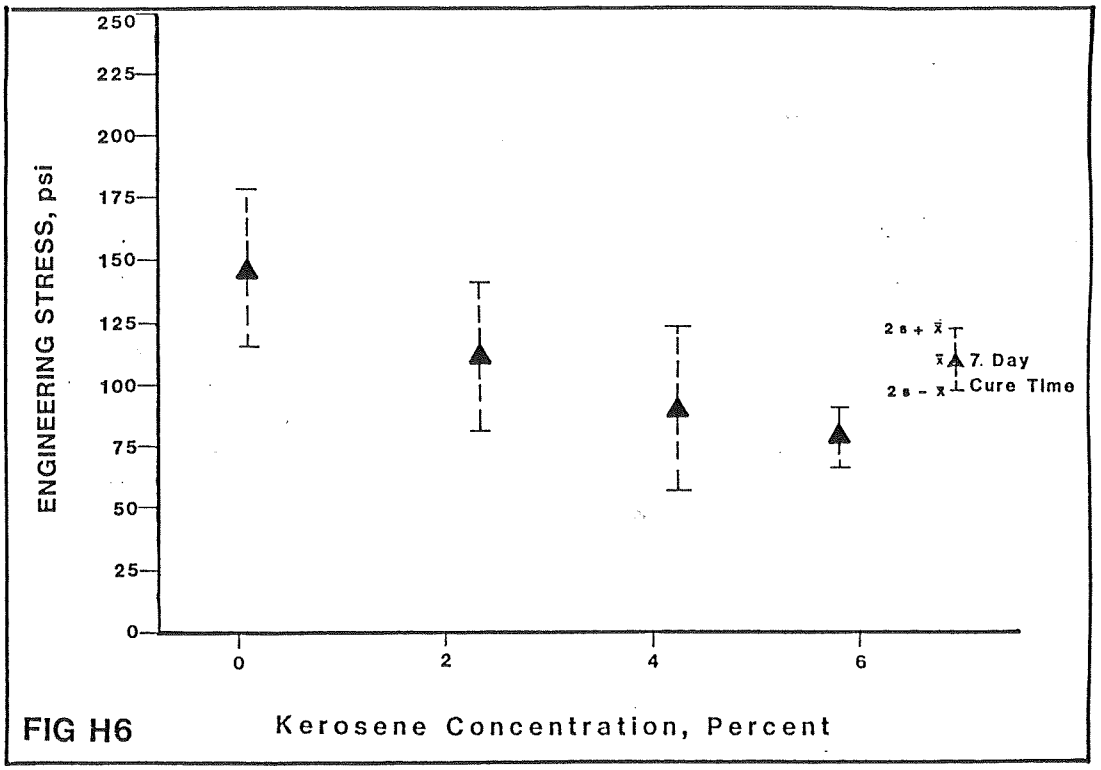
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
2
4
6
2 s + x̄
x̄
7. Day
2 s - x̄
Cure Time
Kerosene Concentration, Percent

FIG H6

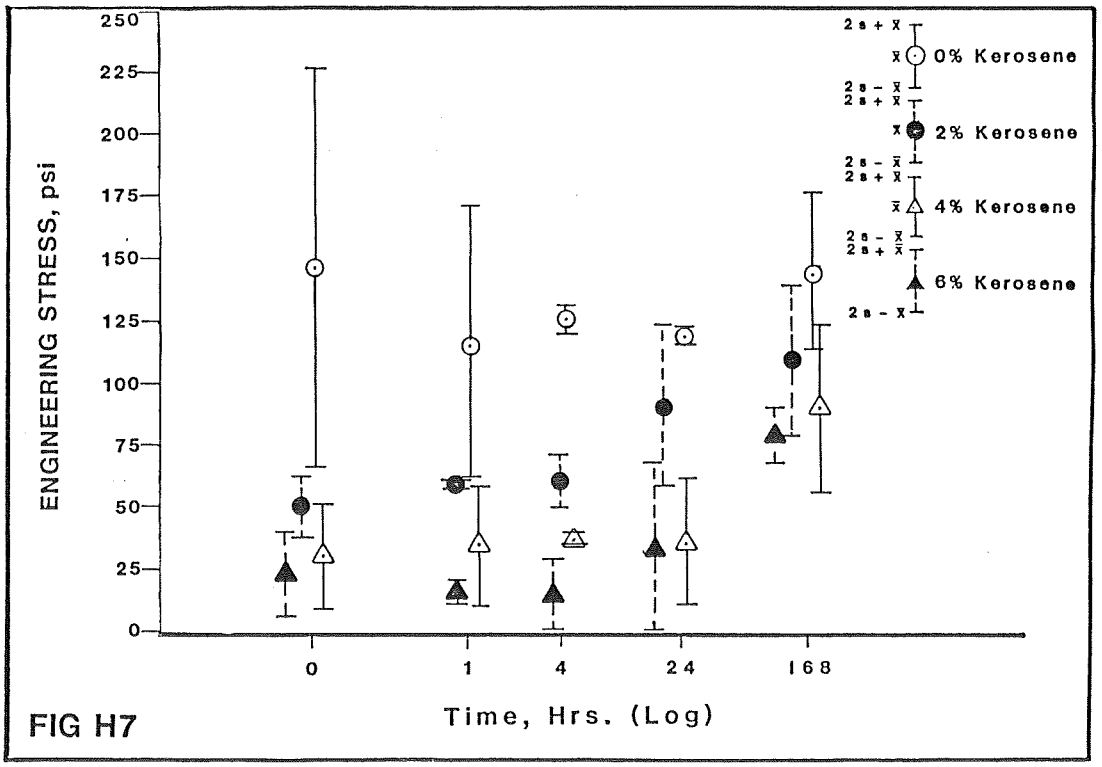
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
1
4
24
168
2 s + x̄
x̄
0% Kerosene
2 s - x̄
2 s + x̄
x̄
2% Kerosene
2 s - x̄
2 s + x̄
x̄
4% Kerosene
2 s - x̄
2 s + x̄
6% Kerosene
2 s - x̄
Time, Hrs. (Log)

FIG H7

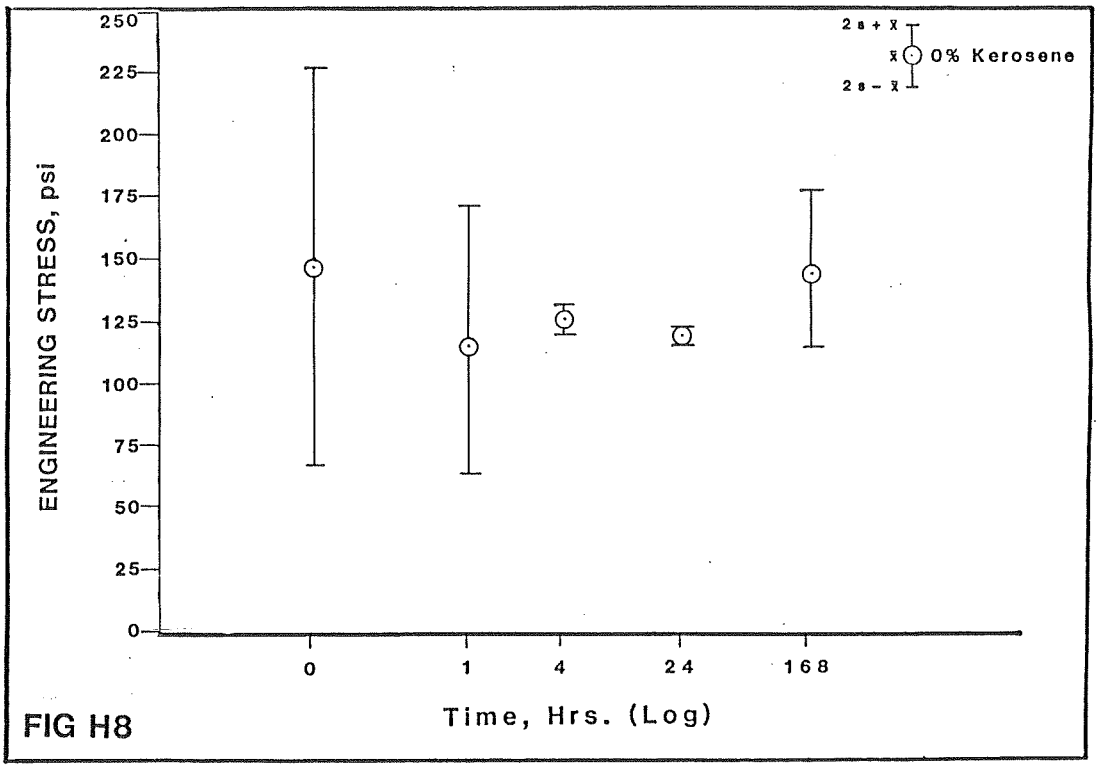
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
1
4
24
168
Time, Hrs. (Log)
2s + x̄
x̄
2s - x̄
0% Kerosene

FIG H8

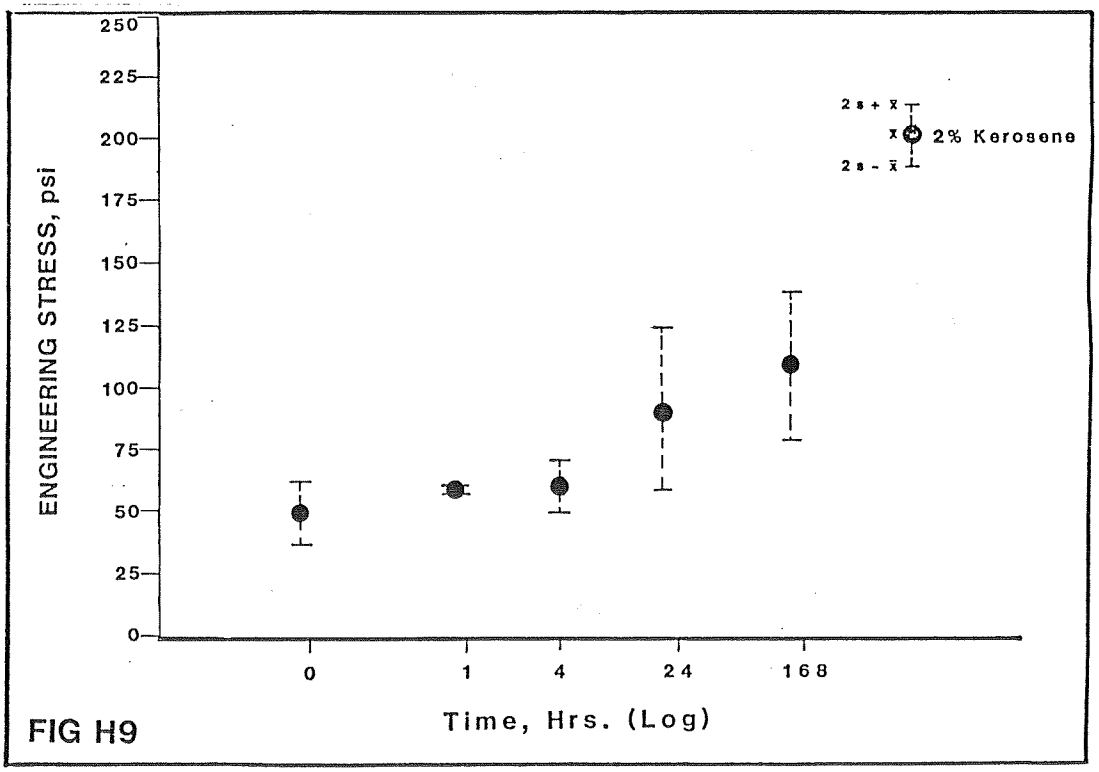
ENGINEERING STRESS, psi
250
225
200
175
150
125
100
75
50
25
0
0
1
4
24
168
Time, Hrs. (Log)
2s + x̄
x̄
2s - x̄
2% Kerosene

FIG H9

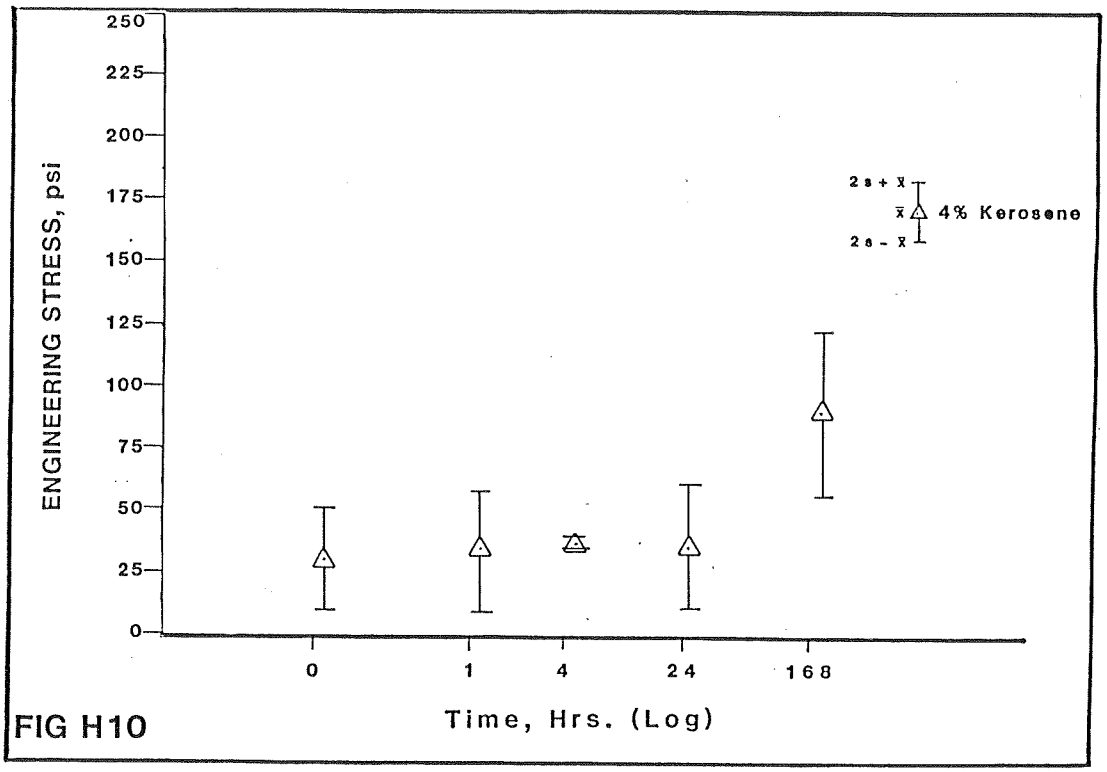

FIG H10

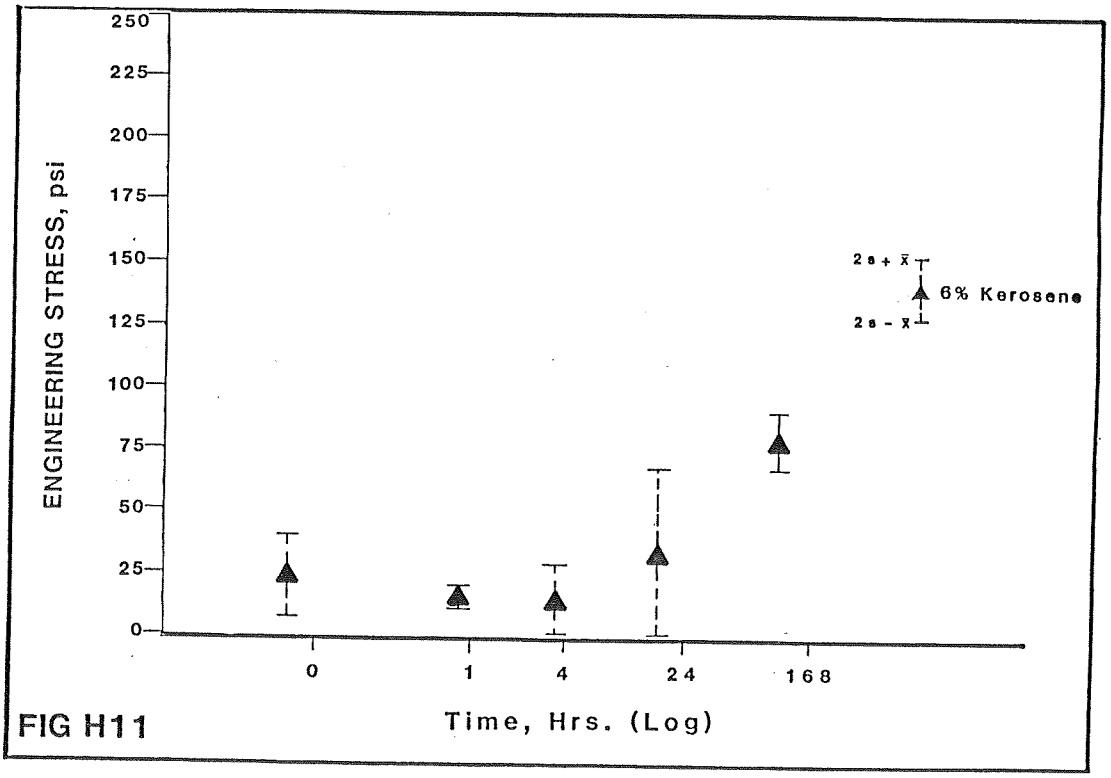

FIG H11

APPENDIX I

FORCE-DUCTILITY ENGINEERING STRAIN AT FAILURE AT 39.2F (4C)

Table I-1 Engineering Strain at Failure, mm/mm

a. Measured Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	2.60 3.46 2.82	3.68 4.24 3.80	3.86 4.29 3.41	4.04 3.20 3.69	3.66 3.49 3.46
	3.48 3.04 3.41	2.24 3.14 2.30	3.38 3.40 3.28	5.16 2.90 3.68	3.25 3.37 3.15
2% 410 H	2.90 3.30 3.10	3.54 2.43 2.98	3.37 2.86 4.08	3.94 3.57 4.34	3.08 3.33 3.61
	4.78 4.02 3.92	4.46 4.22 4.10	3.65 3.92 4.17	1.36 3.51 3.61	2.98 3.06 2.69
4% 410 H	2.52 2.26 5.04	3.14 3.30 3.26	2.90 2.72 3.56	4.35 3.78 4.10	3.66 3.49 3.96
	2.92 3.58 3.25	3.35 3.82 2.46	3.43 3.43 4.18	3.25 3.43 3.29	3.18 3.62 3.67
6% 410 H	3.45 4.80 3.88	4.52 3.08 5.79	3.28 3.38 3.42	2.16 3.12 4.40	3.60 3.24 3.80
	3.80 4.72 4.00	3.70 2.98 2.21	2.41 3.08 1.68	3.86 4.10 3.88	4.32 3.80 3.71

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	3.135	3.233	3.603	3.778	3.397
	s	.3728	.8247	.3926	.7875	.1817
	cv	11.89	25.51	10.89	20.84	5.35
2% 410 H	$\bar{x}$	3.670	3.622	3.675	3.388	3.125
	s	.7031	.7910	.4954	1.0413	.3143
	cv	19.16	21.84	13.48	30.73	10.06
4% 410 H	$\bar{x}$	3.262	3.222	3.370	3.700	3.597
	s	.9934	.4402	.5182	.4544	.2557
	cv	30.46	13.66	15.38	12.28	7.11
6% 410 H	$\bar{x}$	4.108	3.713	2.875	3.587	3.745
	s	.5376	1.2777	.6932	.8172	.3504
	cv	13.08	34.41	24.11	22.78	9.36

Table I-2 Engineering Strain at Failure, mm/mm

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	2.960 / 3.310	3.907 / 2.560	3.853 / 3.353	3.643 / 3.913	3.537 / 3.257
2% 410 H	3.100 / 4.240	2.983 / 4.260	3.437 / 3.913	3.950 / 2.827	3.340 / 2.910
4% 410 H	3.273 / 3.250	3.233 / 3.210	3.060 / 3.680	4.077 / 3.323	3.703 / 3.490
6% 410 H	4.043 / 4.173	4.463 / 2.963	3.360 / 2.390	3.227 / 3.947	3.547 / 3.943

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	3.135	3.234	3.603	3.778	3.397
	s	3.101	1.1934	.4430	.2392	.2481
	cv	9.89	36.91	12.30	6.33	7.30
2% 410 H	$\bar{x}$	3.670	3.622	3.675	3.119	3.125
	s	1.0100	1.1314	.4217	1.4734	.3810
	cv	27.52	31.24	11.48	47.25	12.19
4% 410 H	$\bar{x}$	3.262	3.222	3.370	3.700	3.597
	s	.0204	.0204	.5493	.6680	.1887
	cv	.63	.63	16.30	18.06	5.25
6% 410 H	$\bar{x}$	4.108	3.713	2.875	3.587	3.745
	s	.1152	1.3290	.8594	.6379	.3509
	cv	2.80	35.79	29.89	17.78	9.37

Table I-3 ANOVA Summary, Engineering Strain at Failure

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	.20696	.06899	.233	3.10	4.94
Tj	4	.25945	.06486	.219	2.87	4.43
(CT)ij	12	2.73780	.22815	.772	2.28	3.23
Error	20	5.91180	.29559			
TOTAL	39	9.11591				

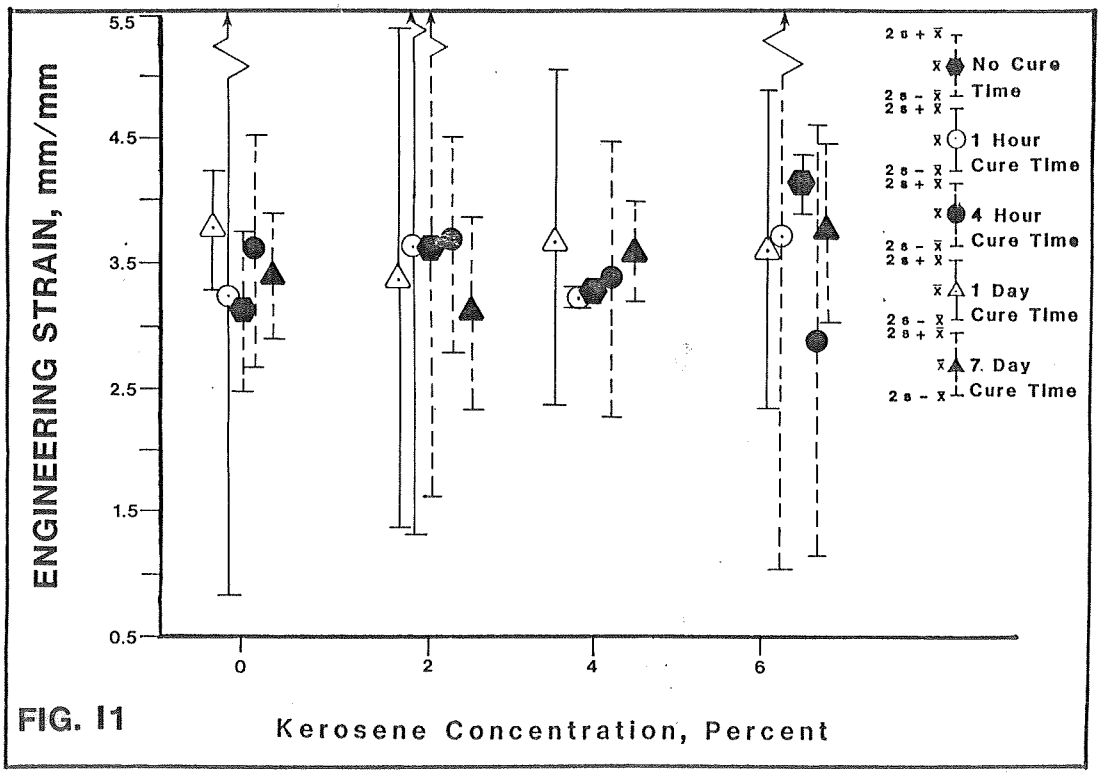

FIG. I1

APPENDIX J

FORCE-DUCTILITY TRUE STRESS AT FAILURE AT 39.2F (4C)

Table J-1 True Stress at Failure, psi

a. Measured Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	406.5 594.3 498.1	567.7 680.0 710.6	595.3 707.2 581.9	635.1 456.6 601.0	670.3 636.7 573.8
	767.9 710.8 729.5	256.9 533.2 330.4	542.4 552.3 553.7	673.4 449.9 624.4	634.9 737.9 620.5
2% 410 H	198.7 242.1 230.1	269.3 213.1 241.3	263.7 234.1 293.5	558.6 399.1 567.0	408.0 437.6 494.4
	319.4 215.8 224.7	284.3 318.3 360.7	273.2 327.5 368.5	209.3 330.3 425.8	481.5 493.7 431.1
4% 410 H	118.8 144.0 185.2	203.9 152.3 180.3	143.4 154.3 189.2	153.6 152.5 148.0	375.8 362.0 409.1
	92.8 120.7 100.7	108.8 164.3 98.1	169.6 153.3 223.4	192.9 184.4 200.5	410.1 523.2 410.8
6% 410 H	146.4 164.4 135.8	78.6 86.2 158.4	121.4 69.0 94.2	109.3 206.9 268.4	330.7 374.0 429.8
	78.0 117.1 113.3	82.8 62.1 58.2	52.0 44.4 31.9	113.4 121.5 147.5	343.2 420.5 381.7

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	617.9	513.1	588.8	573.4	645.7
	s	143.655	183.992	61.361	95.983	54.970
	cv	23.25	35.86	10.42	16.74	8.51
2% 410 H	$\bar{x}$	238.5	281.2	293.4	415.0	457.7
	s	42.233	53.061	48.186	136.81	36.854
	cv	17.71	18.87	16.42	32.96	8.05
4% 410 H	$\bar{x}$	127.0	151.3	172.2	172.0	416.7
	s	33.599	41.023	29.747	23.228	60.235
	cv	26.45	27.12	17.27	13.51	14.46
6% 410 H	$\bar{x}$	125.8	87.7	68.8	161.2	380.0
	s	30.120	36.423	33.619	63.754	39.860
	cv	23.94	41.52	48.84	39.56	10.49

Table J-2 True Stress at Failure, psi

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	499.63 / 736.07	652.77 / 373.50	628.13 / 549.47	564.23 / 582.57	626.93 / 664.43
2% 410 H	223.63 / 253.30	241.23 / 321.10	263.77 / 323.07	508.23 / 321.80	446.67 / 468.77
4% 410 H	149.33 / 104.73	178.83 / 123.73	162.30 / 182.10	151.37 / 192.60	382.30 / 451.03
6% 410 H	148.87 / 102.73	107.73 / 67.70	94.87 / 42.77	194.87 / 127.47	378.17 / 381.80

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	617.85	513.14	588.80	573.40	645.68
	s	209.486	247.433	69.693	16.249	33.225
	cv	33.91	48.22	11.84	2.83	5.15
2% 410 H	$\bar{x}$	238.47	281.17	293.42	415.02	457.72
	s	26.288	70.765	52.540	165.177	19.581
	cv	11.02	25.17	17.91	39.80	4.28
4% 410 H	$\bar{x}$	127.03	151.28	172.20	171.99	416.67
	s	39.516	48.819	17.543	36.530	60.895
	cv	31.11	32.27	10.19	21.24	14.62
6% 410 H	$\bar{x}$	125.80	87.72	68.82	161.17	379.99
	s	40.880	35.467	46.161	59.716	3.216
	cv	32.50	40.43	67.08	37.05	.85

Table J-3 ANOVA Summary, True Stress at Failure

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	1086209	362069	68.74	3.10	4.94
Tj	4	249647	62411	11.85	2.87	4.43
(CT)ij	12	78968	6580	1.25	2.28	3.23
Error	20	105344	5267	1.25		
TOTAL	39	1520168				

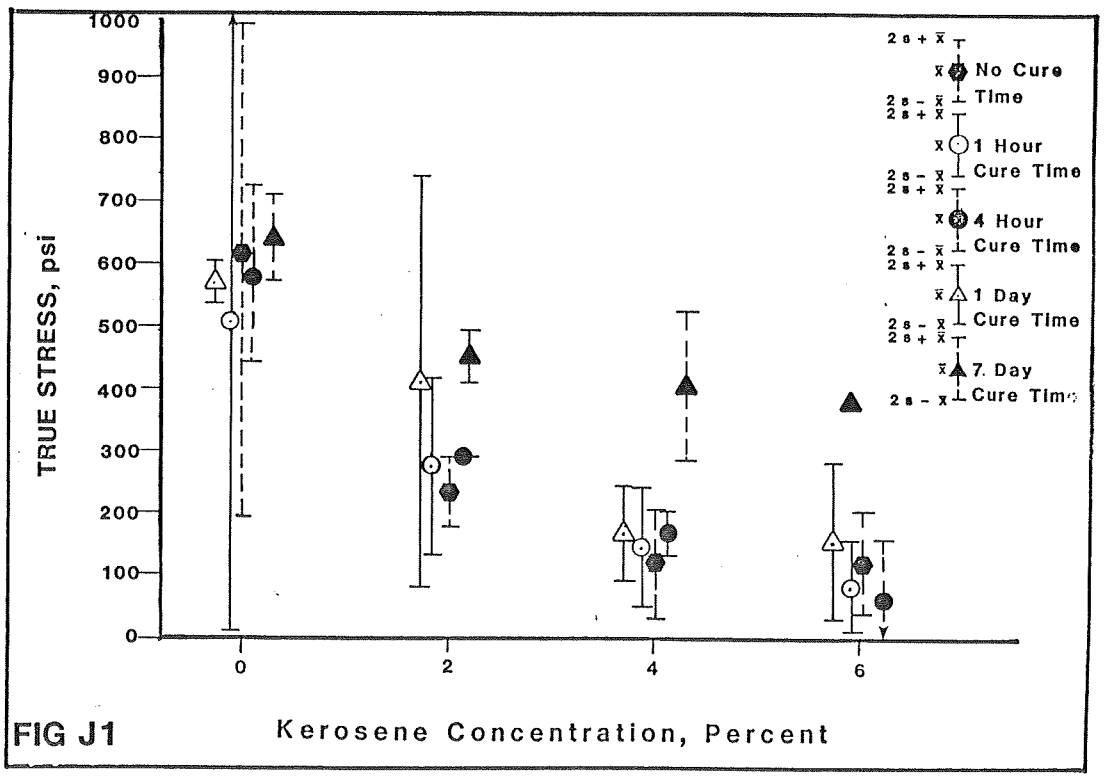

FIG J1

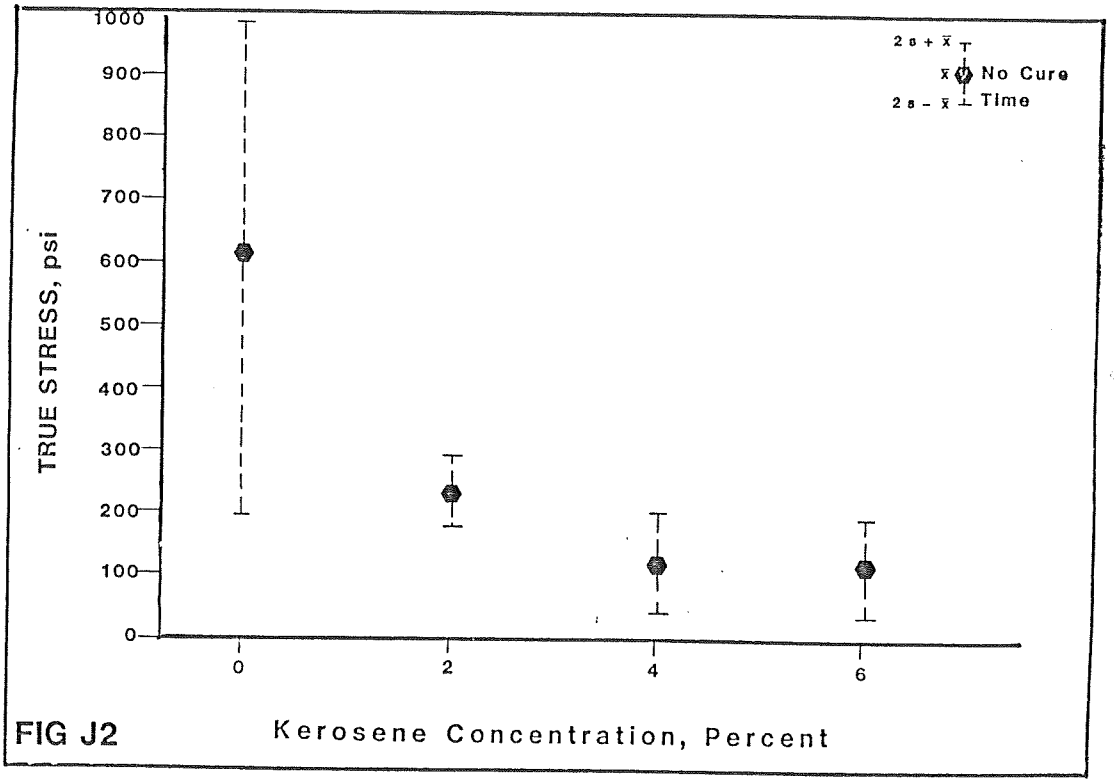
TRUE STRESS, psi
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
2σ + x̄
x̄ No Cure
2σ − x̄ Time
Kerosene Concentration, Percent

FIG J2

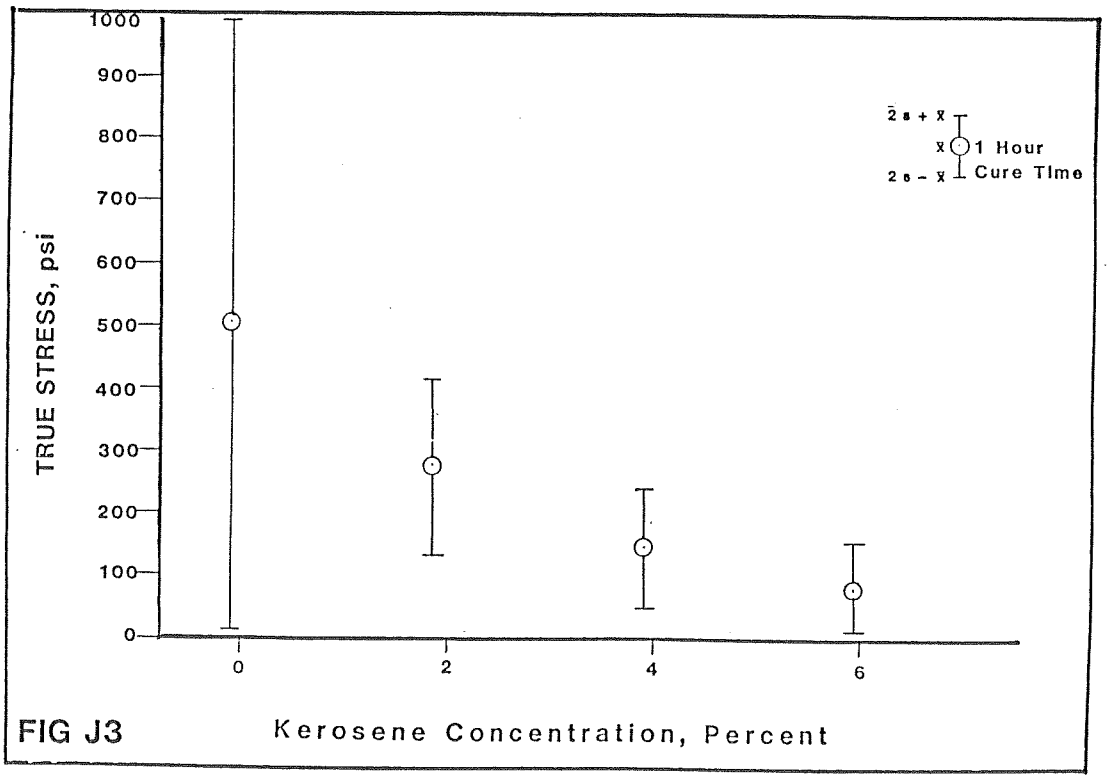
TRUE STRESS, psi
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
2σ + x̄
x̄ 1 Hour
2σ − x̄ Cure Time
Kerosene Concentration, Percent

FIG J3

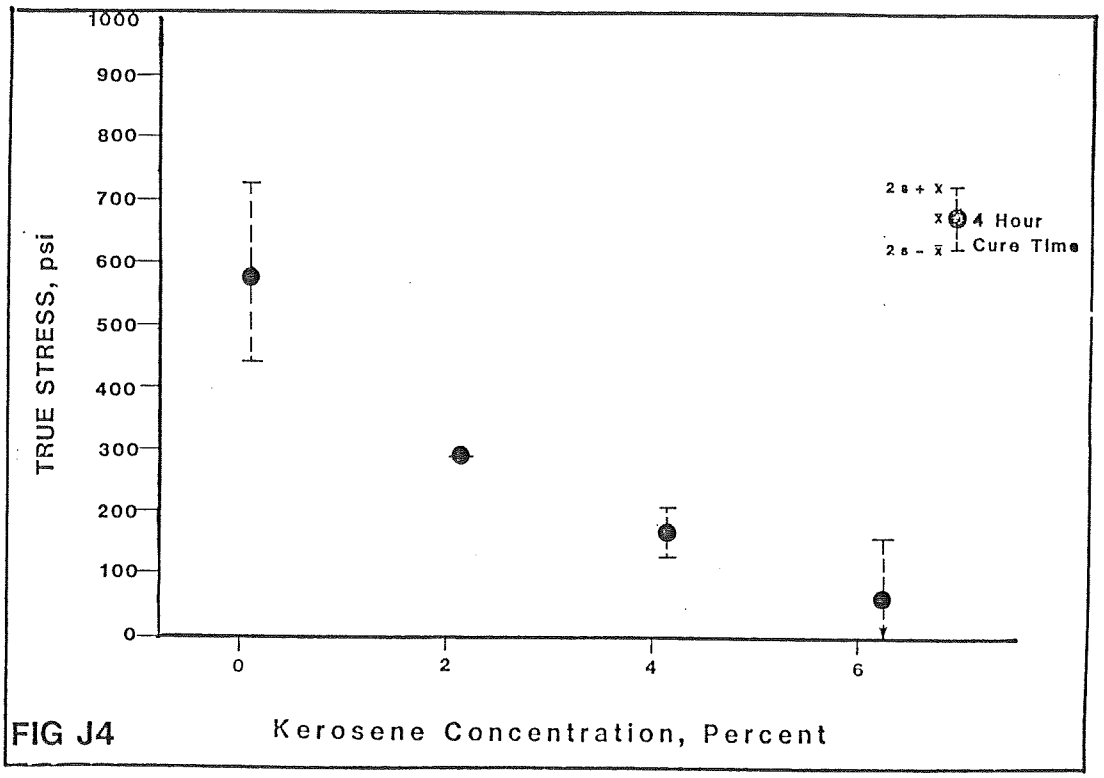
TRUE STRESS, psi
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
2s + x̄
x̄
2s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG J4

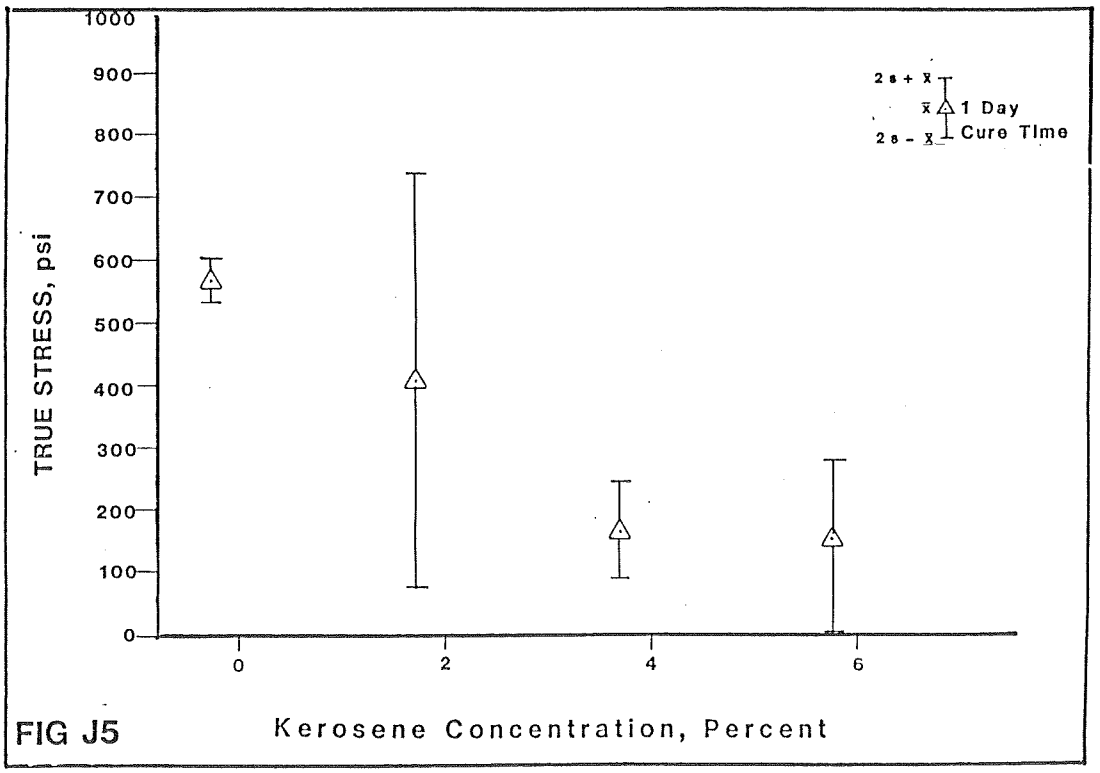
TRUE STRESS, psi
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
2s + x̄
x̄
2s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG J5

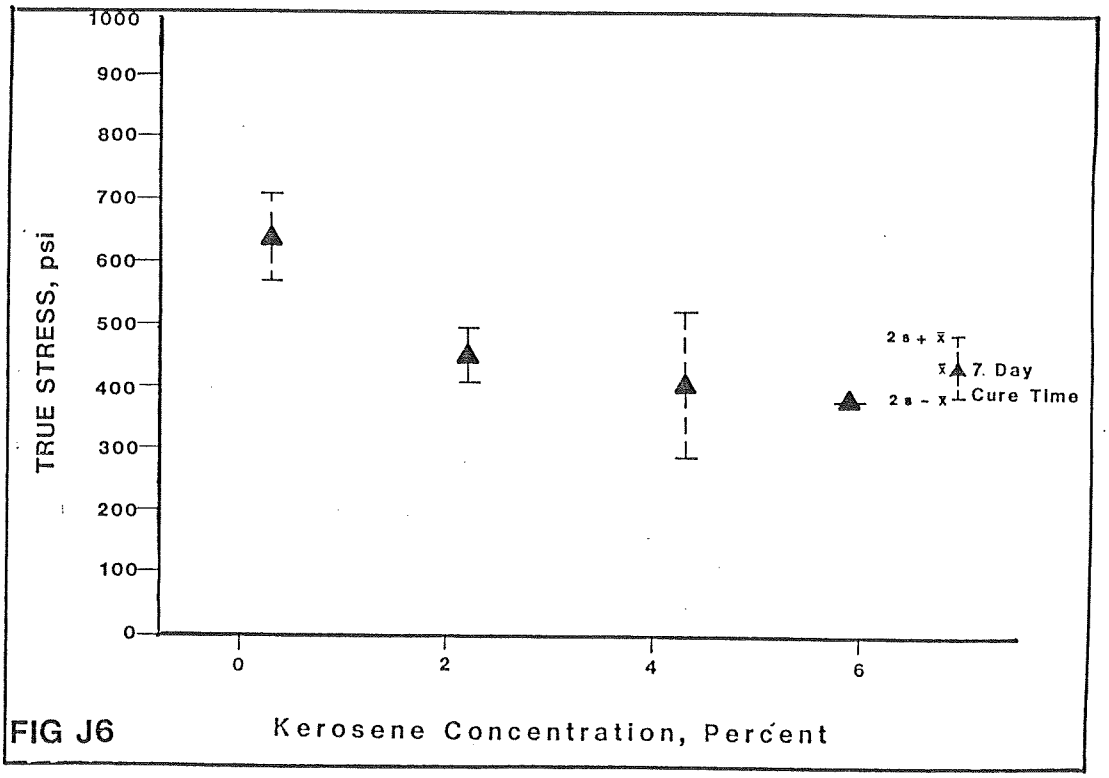
TRUE STRESS, psi
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
2 s + x̄
x̄
7. Day
Cure Time
2 s - x̄
Kerosene Concentration, Percent

FIG J6

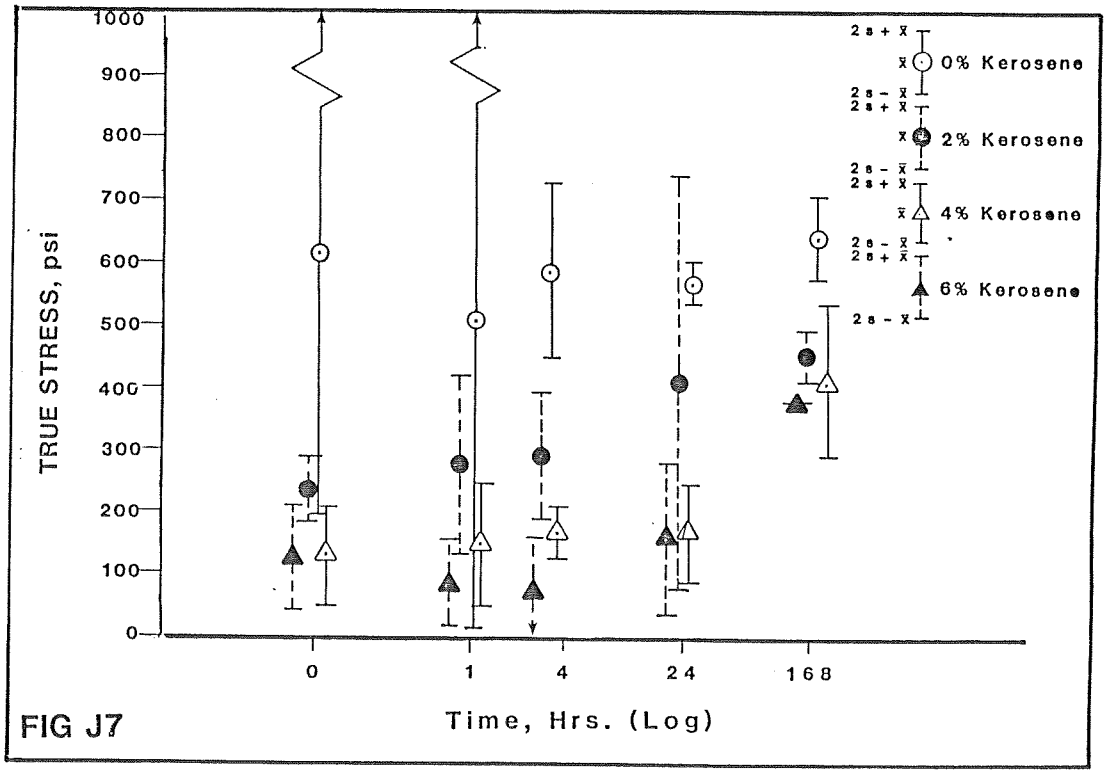
TRUE STRESS, psi
1000
900
800
700
600
500
400
300
200
100
0
0
1
4
24
168
2 s + x̄
x̄
0% Kerosene
2 s - x̄
2 s + x̄
x̄
2% Kerosene
2 s - x̄
2 s + x̄
x̄
4% Kerosene
2 s - x̄
2 s + x̄
6% Kerosene
2 s - x̄
Time, Hrs. (Log)

FIG J7

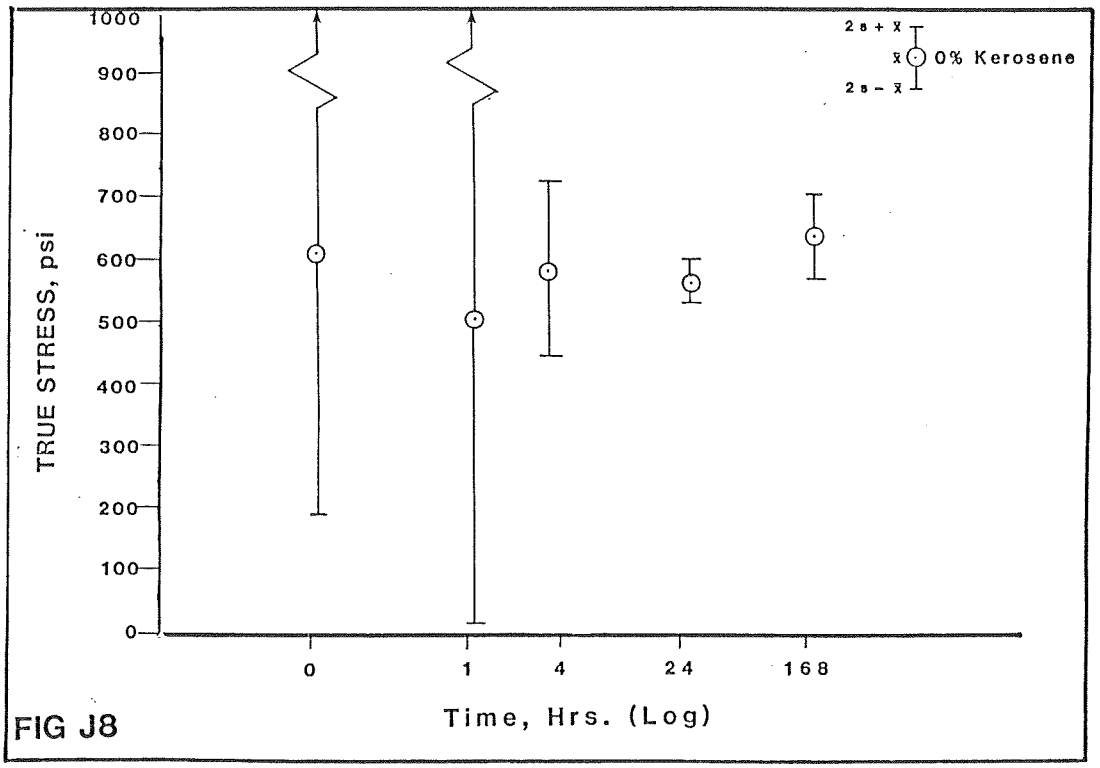
1000
900
800
700
600
500
400
300
200
100
0
TRUE STRESS, psi
0
1
4
24
168
Time, Hrs. (Log)
2s + x̄
x̄
2s - x̄
0% Kerosene

FIG J8

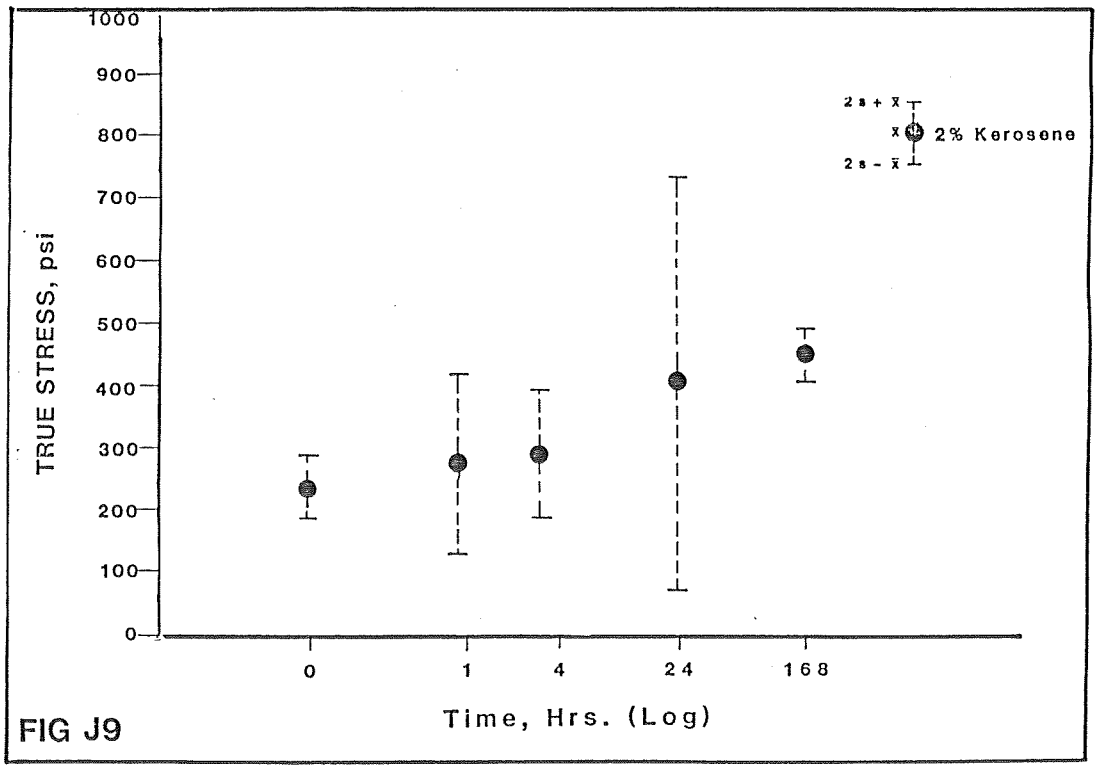
1000
900
800
700
600
500
400
300
200
100
0
TRUE STRESS, psi
0
1
4
24
168
Time, Hrs. (Log)
2s + x̄
x̄
2s - x̄
2% Kerosene

FIG J9

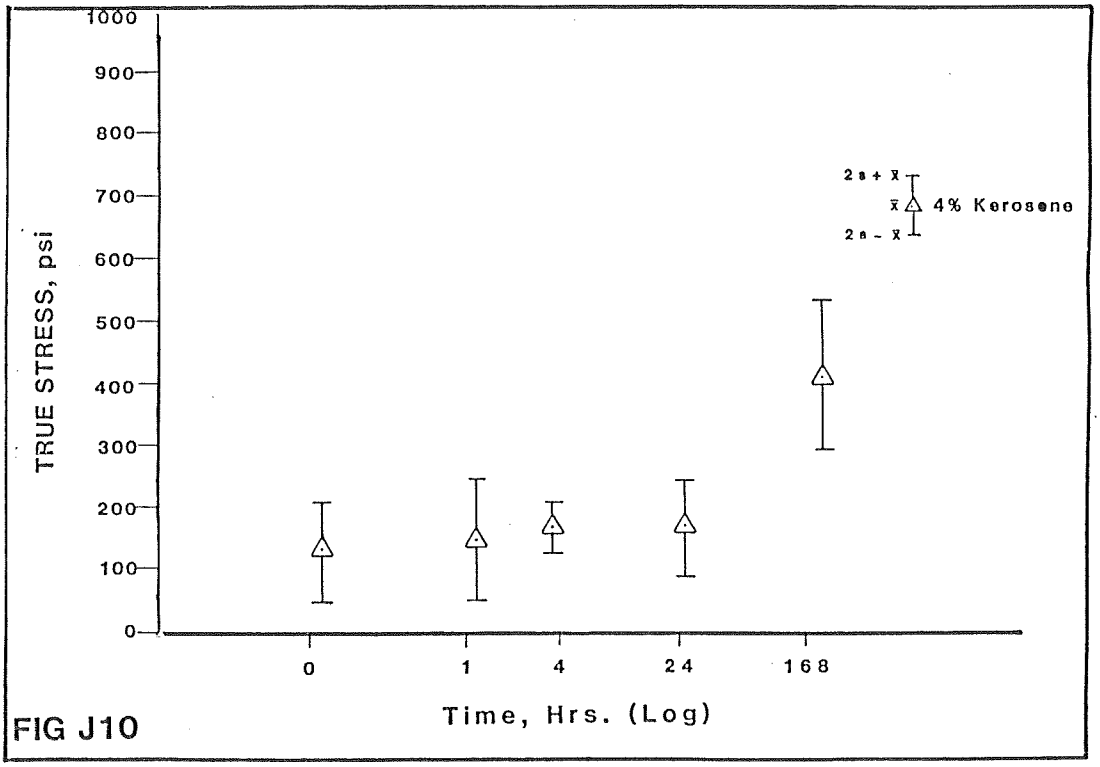

FIG J10

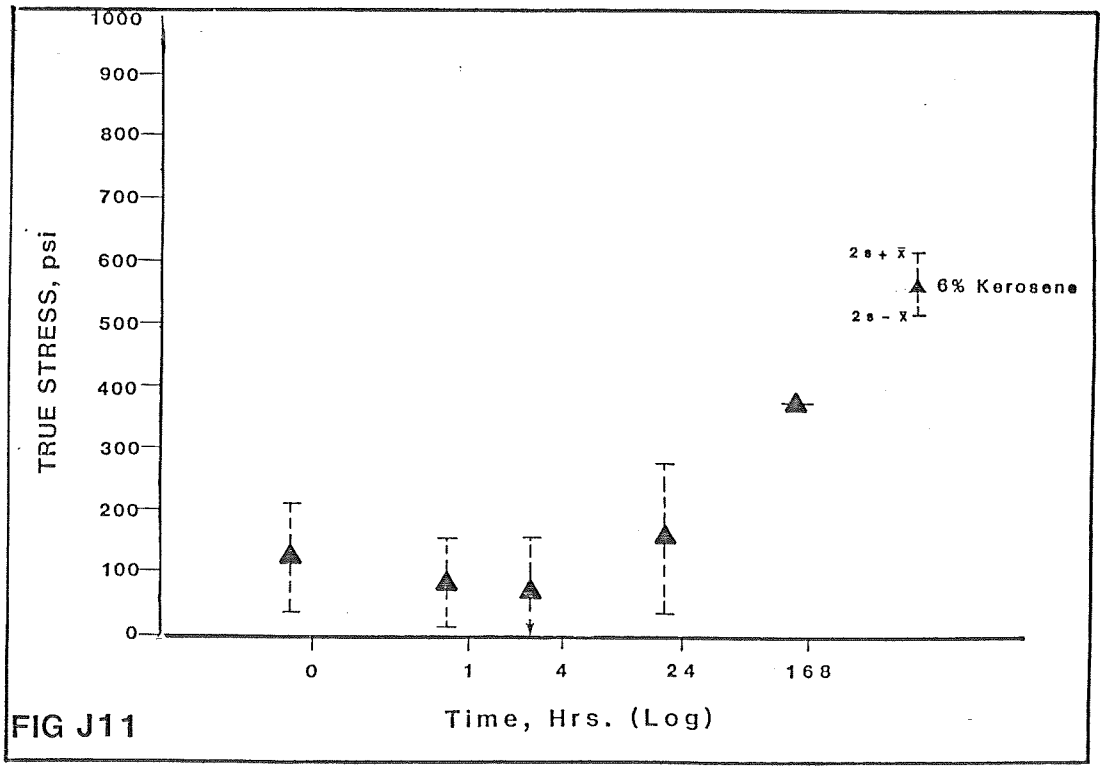

FIG J11

APPENDIX K

FORCE-DUCTILITY TRUE STRAIN

AT FAILURE AT 39.2F (4C)

Table K-1 True Strain at Failure, mm/mm

a. Measured Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	1.28 1.50 1.34	1.54 1.66 1.57	1.58 1.67 1.48	1.62 1.44 1.55	1.54 1.50 1.49
	1.50 1.40 1.48	1.18 1.42 1.19	1.48 1.48 1.45	1.80 1.36 1.54	1.45 1.47 1.42
2% 410 H	1.36 1.46 1.41	1.51 1.23 1.38	1.48 1.35 1.63	1.60 1.52 1.68	1.41 1.47 1.53
	1.75 1.61 1.59	1.70 1.65 1.63	1.54 1.59 1.64	0.86 1.51 1.53	1.38 1.40 1.30
4% 410 H	1.26 1.18 1.80	1.42 1.46 1.45	1.36 1.31 1.52	1.68 1.56 1.63	1.54 1.50 1.60
	1.37 1.52 1.45	1.47 1.57 1.24	1.49 1.49 1.64	1.45 1.49 1.46	1.43 1.53 1.54
6% 410 H	1.49 1.76 1.58	1.71 1.41 1.92	1.45 1.48 1.49	1.15 1.42 1.69	1.53 1.44 1.57
	1.57 1.74 1.61	1.55 1.38 1.17	1.23 1.41 0.99	1.58 1.63 1.59	1.67 1.57 1.55

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	1.42	1.43	1.52	1.55	1.48
	s	.0925	.2024	.0845	.1521	.0417
	cv	6.53	14.18	5.55	9.80	2.82
2% 410 H	$\bar{x}$	1.53	1.53	1.54	1.45	1.42
	s	.1460	.1817	.1098	.2961	.0787
	cv	9.54	11.98	7.14	20.42	5.56
4% 410 H	$\bar{x}$	1.43	1.44	1.47	1.55	1.52
	s	.2193	.1082	.1182	.0948	.0561
	cv	15.33	7.54	8.05	6.14	3.68
6% 410 H	$\bar{x}$	1.63	1.52	1.34	1.51	1.56
	s	.1048	.2650	.1968	.1979	.0742
	cv	6.45	17.40	14.67	13.11	4.77

Table K-2 True Strain at Failure, mm/mm

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	1.373 / 1.460	1.590 / 1.263	1.577 / 1.470	1.537 / 1.567	1.510 / 1.447
2% 410 H	1.410 / 1.650	1.373 / 1.660	1.487 / 1.590	1.600 / 1.300	1.470 / 1.360
4% 410 H	1.413 / 1.447	1.443 / 1.427	1.397 / 1.540	1.623 / 1.467	1.547 / 1.500
6% 410 H	1.610 / 1.640	1.680 / 1.367	1.473 / 1.210	1.420 / 1.600	1.513 / 1.597

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	1.417	1.427	1.523	1.552	1.479
	s	.07708	.28972	.09480	.02658	.05582
	cv	5.44	20.31	6.22	1.71	3.78
2% 410 H	$\bar{x}$	1.530	1.517	1.539	1.450	1.415
	s	.21264	.25428	.09126	.26580	.09746
	cv	13.90	16.77	5.93	18.33	6.89
4% 410 H	$\bar{x}$	1.430	1.435	1.467	1.545	1.524
	s	.03012	.01418	.12670	.13822	.04164
	cv	2.11	.98	8.63	8.95	2.73
6% 410 H	$\bar{x}$	1.625	1.524	1.342	1.510	1.555
	s	.02658	.27731	.23302	.15948	.07442
	cv	1.64	18.20	17.37	10.56	4.79

Table K-3 ANOVA Summary, True Strain at Failure

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	.00645	.00215	.134	3.10	4.94
Tj	4	.01122	.00280	.175	2.87	4.43
(CT)ij	12	.14967	.00125	.780	2.28	3.23
Error	20	.31969	.00160			
TOTAL	39	.48703				

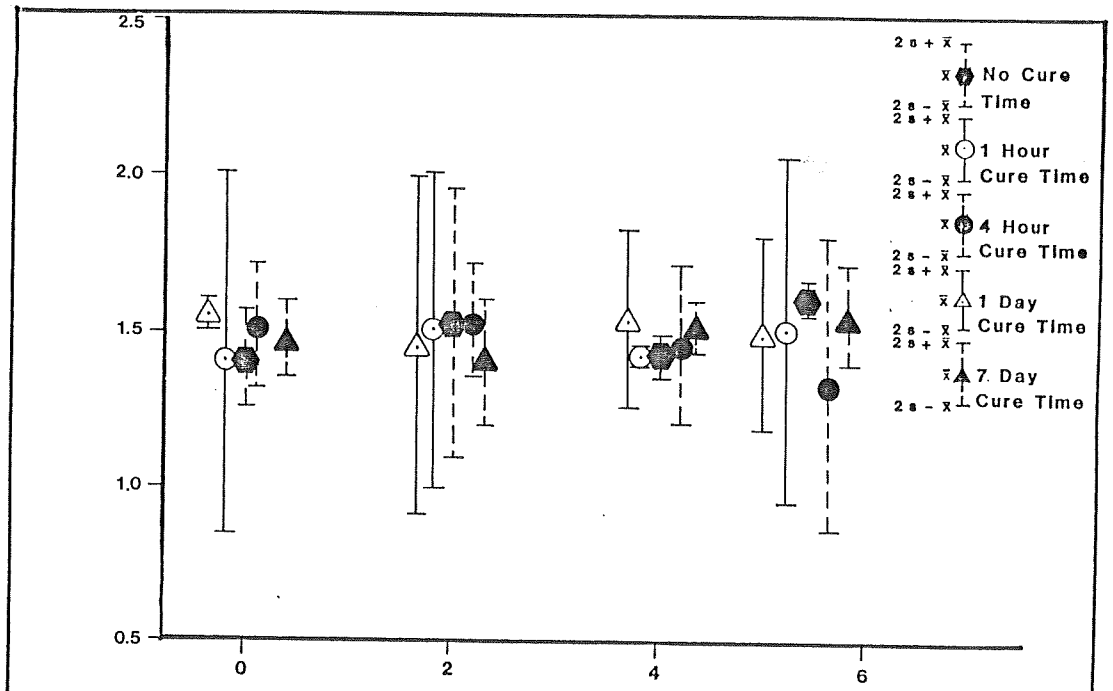

FIG. K1 Kerosene Concentration, Percent

APPENDIX L

FORCE-DUCTILITY ENGINEERING

CREEP COMPLIANCE AT 39.2F (4C)

Table L-1 Engineering Creep Compliance at Failure, psi^{-1}

a. Calculated Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.023 .0260 .0216	.0303 .0326 .0257	.0315 .0322 .0259	.0321 .0294 .0289	.0255 .0246 .0268
	.0203 .0173 .0206	.0282 .0244 .0230	.0273 .0271 .0254	.0472 .0251 .0276	.0218 .0199 .0211
2% 410 H	.0571 .0587 .0553	.0597 .0391 .0491	.0559 .0472 .0706	.0348 .0408 .0409	.0308 .0330 .0337
	.0865 .0935 .0858	.0857 .0692 .0580	.0620 .0590 .0586	.0153 .0479 .0390	.0246 .0251 .0230
4% 410 H	.0747 .0512 .167	.0639 .0932 .0770	.0789 .0656 .0859	.1517 .1189 .1411	.0459 .0433 .0480
	.123 .136 .137	.134 .1121 .0867	.0896 .0992 .0968	.0718 .0823 .0705	.0324 .0320 .0416
6% 410 H	.1048 .169 .139	.317 .146 .2483	.116 .214 .160	.0624 .0621 .0885	.0501 .0367 .0424
	.2334 .2306 .1766	.210 .191 .122	.1578 .2828 .1412	.166 .0172 .0128	.0670 .0435 .0459

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.02147	.02737	.02823	.03172	.02328
	s	.00291	.00367	.00290	.00792	.00274
	cv	13.56	13.41	10.27	24.98	11.75
2% 410 H	$\bar{x}$	.07282	.06013	.05888	.03645	.02837
	s	.01753	.01615	.00765	.01119	.00468
	cv	24.08	26.86	12.99	30.71	16.50
4% 410 H	$\bar{x}$	.11482	.09448	.08600	.10605	.04053
	s	.04333	.02520	.01241	.03600	.00682
	cv	37.74	26.67	14.43	33.94	16.82
6% 410 H	$\bar{x}$	.17557	.20572	.17863	.06817	.04760
	s	.05052	.07072	.06034	.05607	.01047
	cv	28.78	34.38	33.78	82.25	22.00

Table L-2 Engineering Creep Compliance at Failure, psi^{-1}

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.0235 / .0194	.0295 / .0252	.0299 / .0266	.0301 / .0333	.0256 / .0209
2% 410 H	.0570 / .0886	.0493 / .0710	.0579 / .0599	.0388 / .0341	.0325 / .0242
4% 410 H	.0976 / .1320	.0780 / .1109	.0768 / .0952	.1372 / .0749	.0457 / .0353
6% 410 H	.1376 / .2136	.2371 / .1743	.1633 / .1939	.0710 / .0653	.0431 / .0521

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.02145	.02735	.02825	.03170	.02325
	s	.00363	.00381	.00292	.00284	.00416
	cv	16.94	13.93	10.35	8.94	17.91
2% 410 H	$\bar{x}$	.07280	.06015	.05890	.03645	.02835
	s	.02800	.01923	.00177	.00416	.00735
	cv	38.46	31.96	3.01	11.42	25.94
4% 410 H	$\bar{x}$	.11480	.09445	.08600	.10605	.04050
	s	.03048	.02915	.01630	.05520	.00921
	cv	26.55	30.86	18.96	52.05	22.75
6% 410 H	$\bar{x}$	.17560	.20570	.17860	.06815	.04760
	s	.06734	.05564	.02711	.00505	.00797
	cv	38.35	29.05	15.18	7.41	16.75

Table L-3 ANOVA summary, Engineering Creep Compliance at Failure, psi^{-1}

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	.06715	.02238	47.11	3.10	4.94
Tj	4	.02326	.005817	12.24	2.87	4.43
(CT)ij	12	.02755	.002296	4.83	2.28	3.23
Error	20	.009503	.0004751			
TOTAL	39					

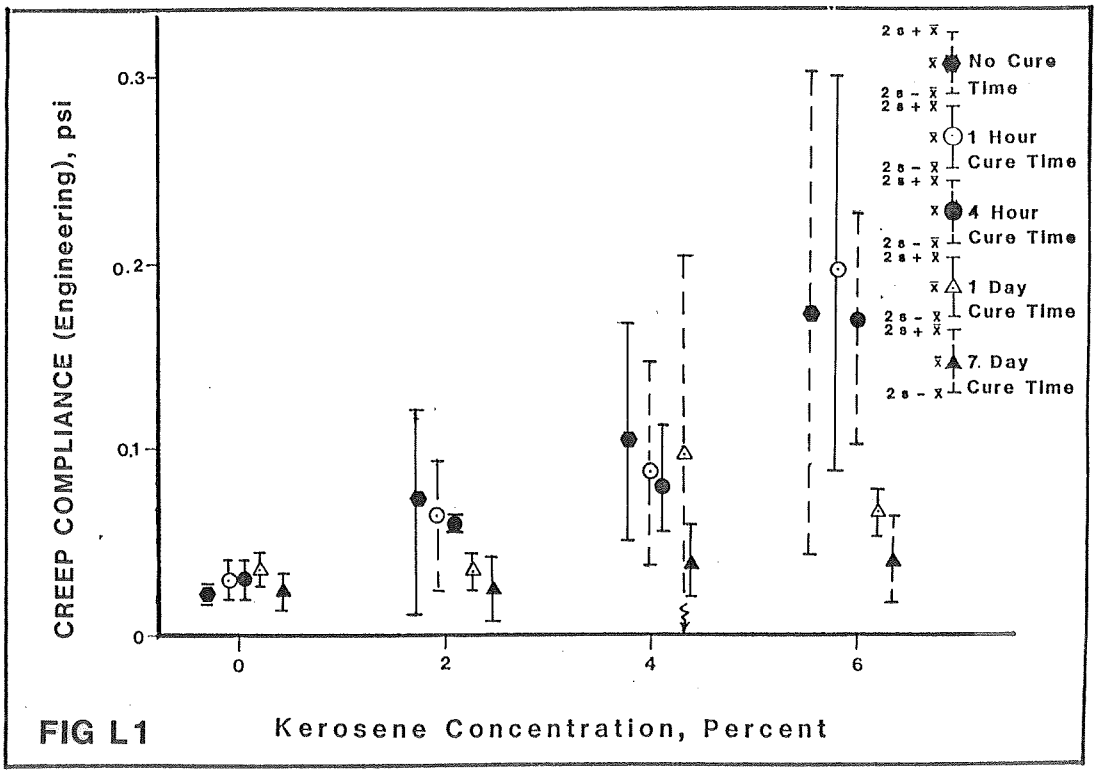

FIG L1

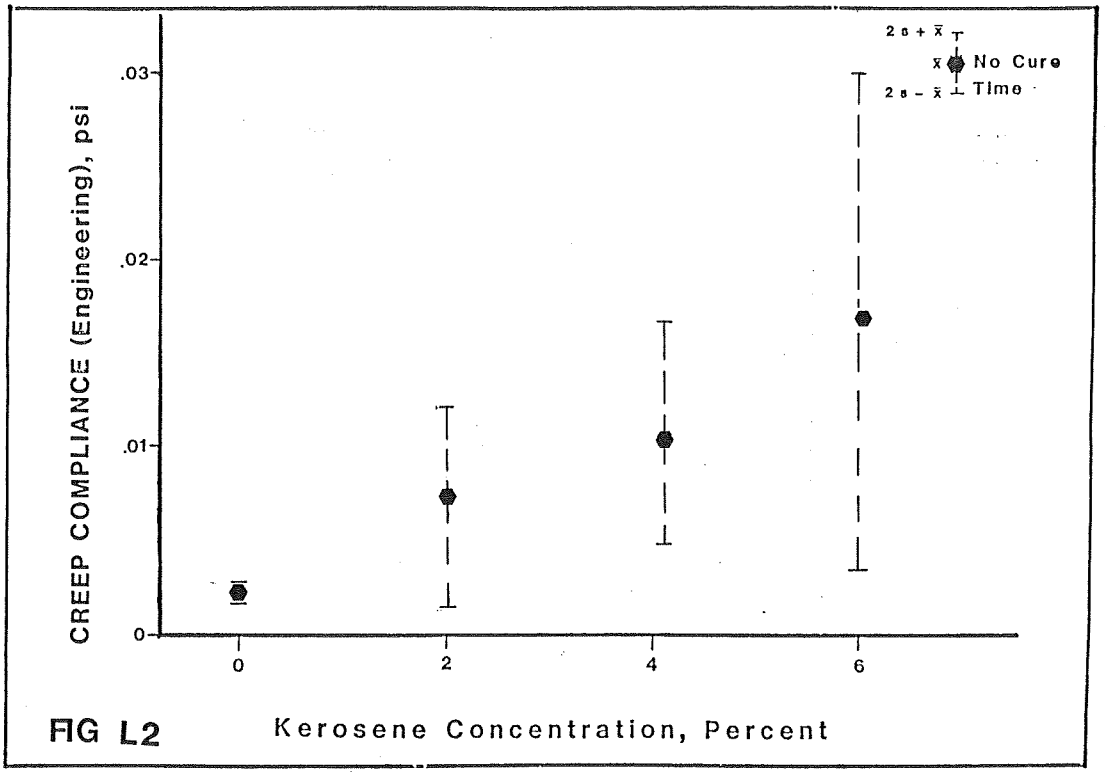
CREEP COMPLIANCE (Engineering), psi
.03
.02
.01
0
0
2
4
6
2 s + x̄
x̄
No Cure
2 s − x̄
Time
Kerosene Concentration, Percent

FIG L2

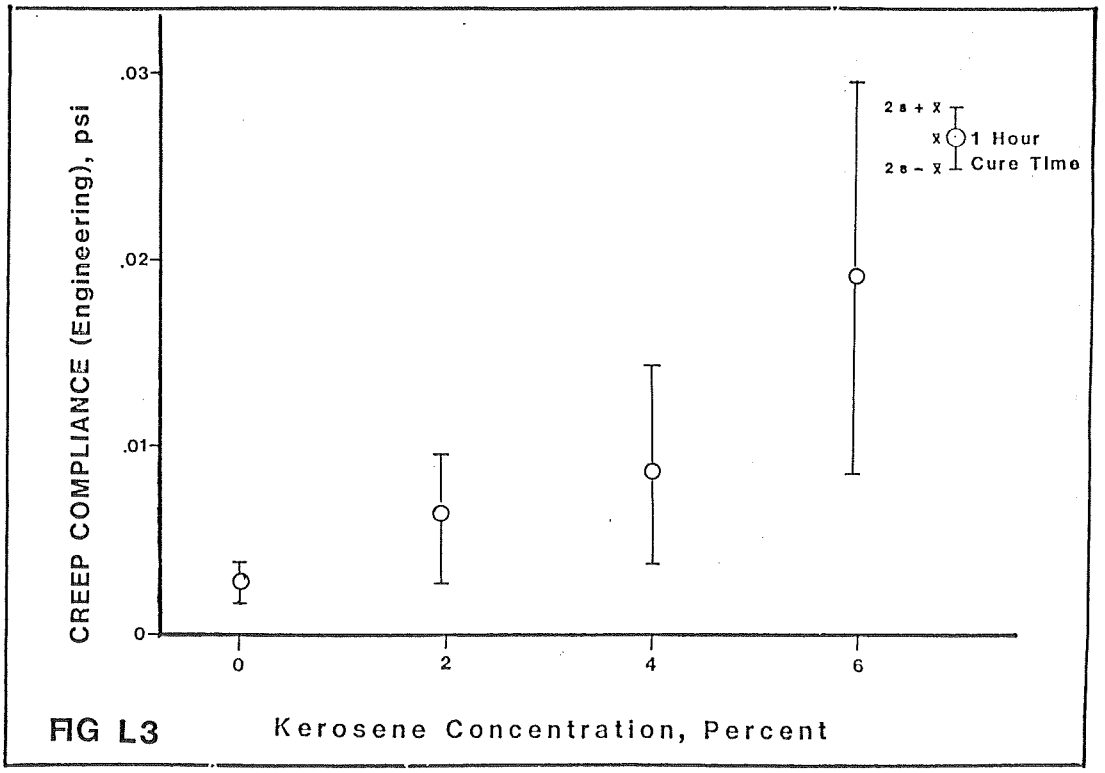
CREEP COMPLIANCE (Engineering), psi
.03
.02
.01
0
0
2
4
6
2 s + x̄
x̄
1 Hour
2 s − x̄
Cure Time
Kerosene Concentration, Percent

FIG L3

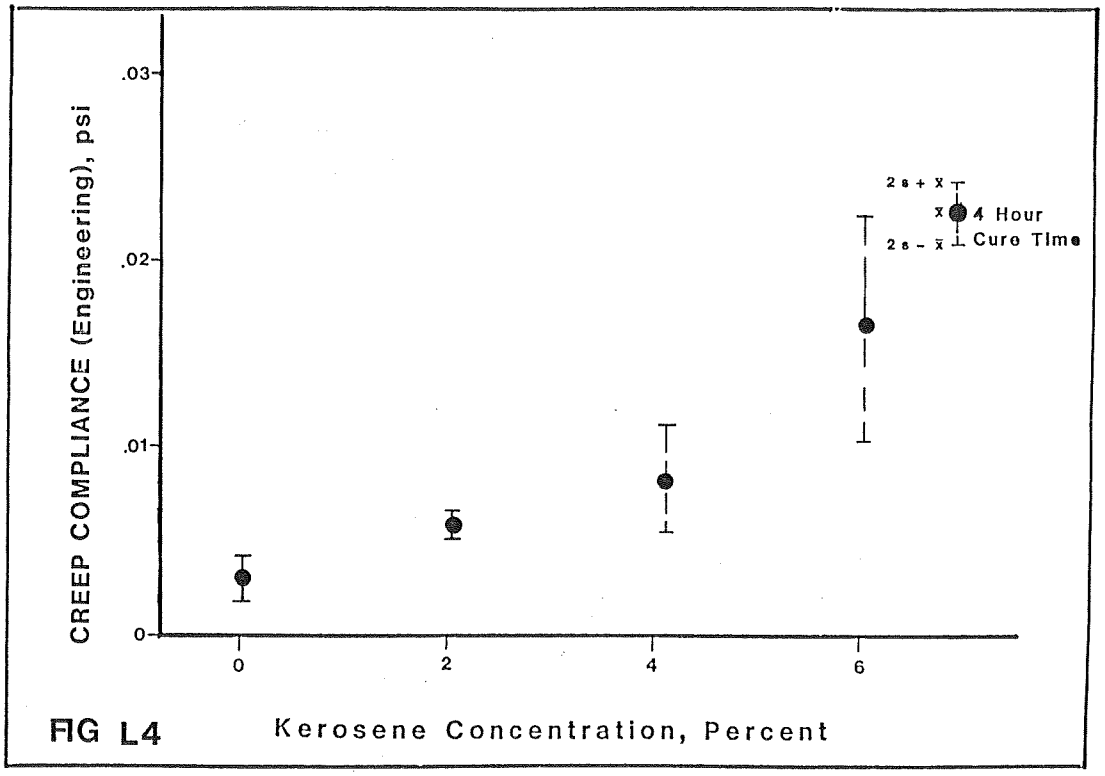
CREEP COMPLIANCE (Engineering), psi
.03
.02
.01
0
0
2
4
6
2 s + x̄
x̄
2 s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG L4

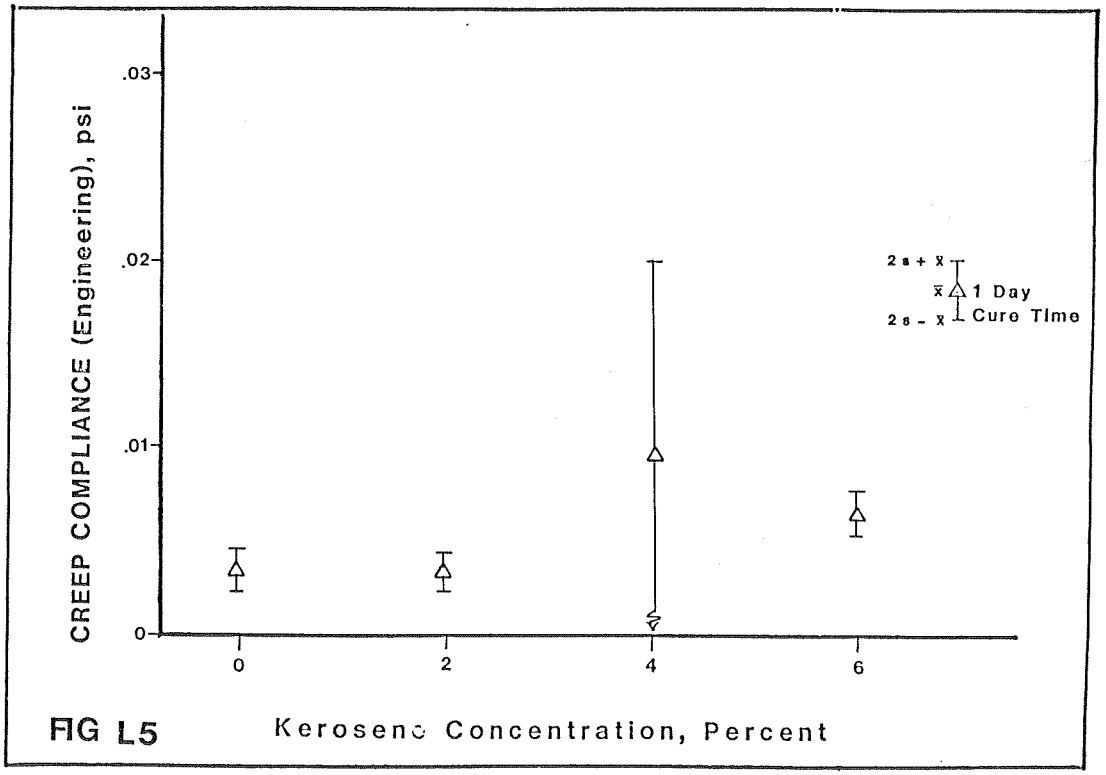
CREEP COMPLIANCE (Engineering), psi
.03
.02
.01
0
0
2
4
6
2 s + x̄
x̄
2 s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG L5

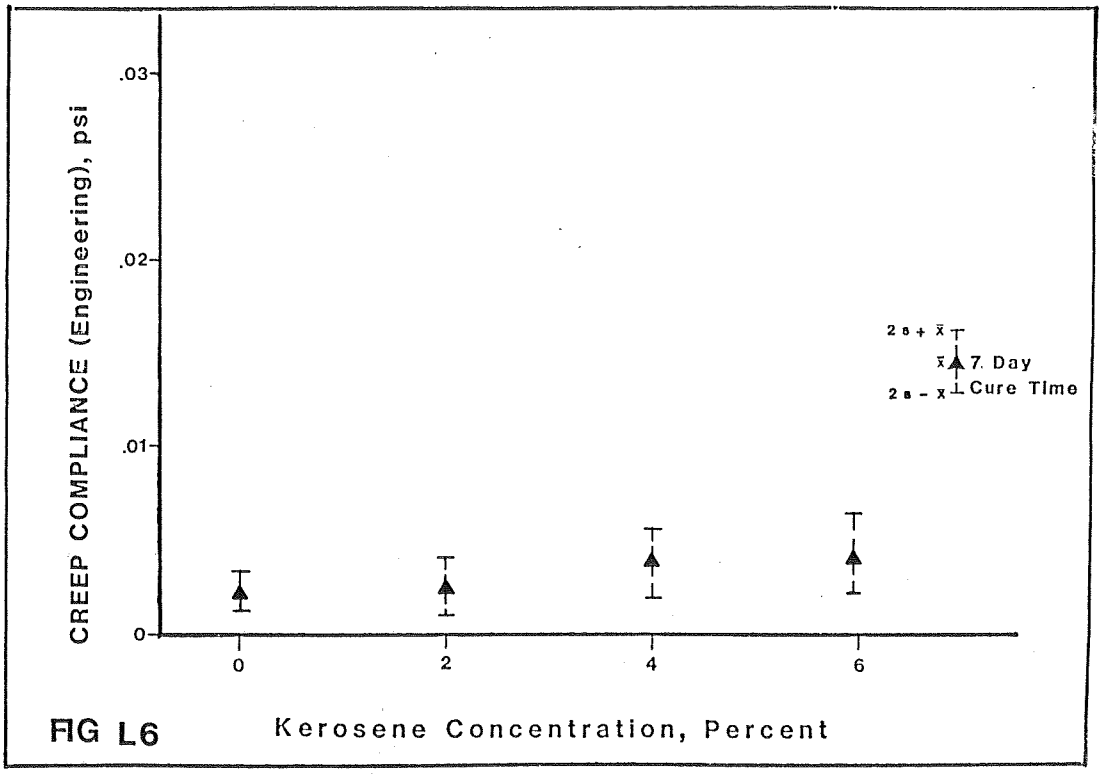
CREEP COMPLIANCE (Engineering), psi
.03
.02
.01
0
0
2
4
6
2 s + x̄
x̄
2 s - x̄
7. Day
Cure Time
Kerosene Concentration, Percent

FIG L6

APPENDIX M

FORCE-DUCTILITY TRUE CREEP COMPLIANCE AT FAILURE AT 39.2F (4C)

Table M-1 True Creep Compliance at Failure, psi^{-1}

a. Calculated Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.0032 .0025 .0027	.00272 .00243 .00221	.00266 .00236 .00255	.0025 .0031 .0026	.00230 .00236 .00260
	.00195 .00196 .00203	.00458 .00267 .00361	.0027 .0027 .0026	.00270 .00302 .00257	.00228 .00200 .00299
2% 410 H	.0069 .0060 .0061	.0056 .0058 .0057	.0056 .0058 .0055	.00286 .00381 .00295	.0034 .0034 .0031
	.00549 .00748 .00709	.00597 .00519 .00452	.0056 .0049 .0045	.00410 .00456 .00359	.00287 .00284 .00303
4% 410 H	.0106 .00821 .00985	.0070 .00958 .00804	.00949 .00851 .0080	.0109 .0103 .0110	.0041 .0041 .0039
	.0147 .0126 .0144	.0135 .00957 .0127	.00878 .00971 .00736	.00751 .00807 .00727	.00349 .00293 .00375
6% 410 H	.0102 .0107 .0117	.0217 .0163 .0121	.0120 .0214 .0158	.0105 .00684 .00628	.00461 .00386 .00365
	.0201 .0149 .0142	.0187 .0223 .0201	.0236 .0317 .0309	.0139 .0134 .0107	.00487 .00373 .00406

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.00239	.00304	.00260	.00273	.00242
	s	.00051	.00089	.00013	.00027	.00034
	cv	21.11	29.44	4.98	9.81	13.96
2% 410 H	$\bar{x}$	.00651	.00546	.00532	.00365	.00311
	s	.00076	.00053	.00050	.00066	.00025
	cv	11.70	9.72	9.47	18.09	7.95
4% 410 H	$\bar{x}$	.01173	.01007	.00864	.00918	.00371
	s	.00260	.00256	.00089	19.00	.00045
	cv	22.21	25.42	10.29	131.22	12.04
6% 410 H	$\bar{x}$	.01363	.01853	.02257	.01027	.00413
	s	.00368	.00382	.00791	.00319	.00050
	cv	27.03	20.63	35.05	31.07	12.09

Table M-2 True Creep Compliance at Failure, psi^{-1}

a. Reduced Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.00280	.00245	.00252	.00273	.00242
	.00198	.00362	.00267	.00273	.00242
2% 410 H	.00633	.00570	.00563	.00321	.00330
	.00669	.00523	.00500	.00408	.00291
4% 410 H	.00955	.00821	.00867	.01073	.00403
	.01390	.01192	.00862	.00762	.00339
6% 410 H	.01087	.01670	.01640	.00787	.00404
	.0164	.02037	.02873	.01267	.00422

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.00239	.00304	.00260	.00273	.00242
	s	.00073	.00104	.00013	0	0
	cv	30.40	34.16	5.12	0	0
2% 410 H	$\bar{x}$	.00651	.00547	.00532	.00365	.00311
	s	.00032	.00042	.00056	.00077	.00035
	cv	4.90	7.62	10.50	21.15	11.13
4% 410 H	$\bar{x}$	.01173	.01007	.00865	.00918	.00371
	s	.00385	.00329	.00004	.00276	.00057
	cv	32.87	32.66	.51	30.03	15.28
6% 410 H	$\bar{x}$	.01364	.01854	.02257	.01027	.00413
	s	.00490	.00325	.01092	.00425	.00016
	cv	35.93	17.54	48.41	41.41	3.86

Table M-3 ANOVA Summary, True Creep Compliance at Failure

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	.0007231	.0002410	36.29	3.10	4.94
Tj	4	.0002230	.00005574	8.39	2.87	4.43
(CT)ij	12	.0002760	.00002300	3.46	2.28	3.23
Error	20	.0001328	.00000664			
TOTAL	39					

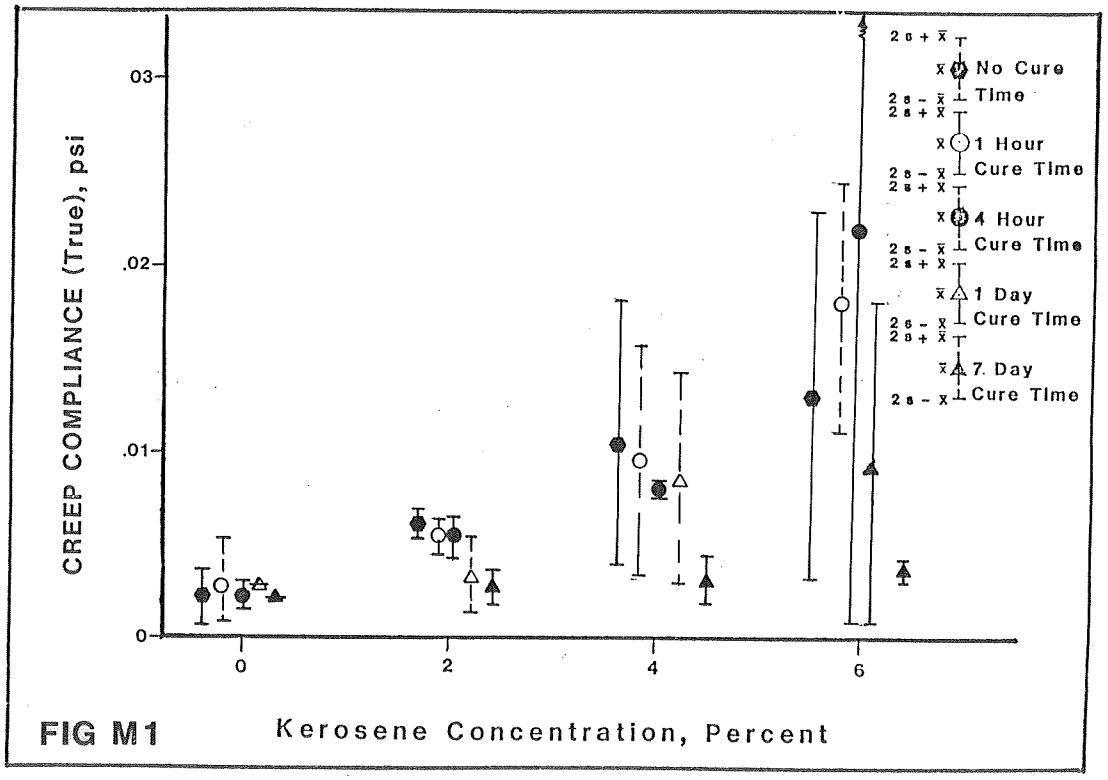

FIG M1

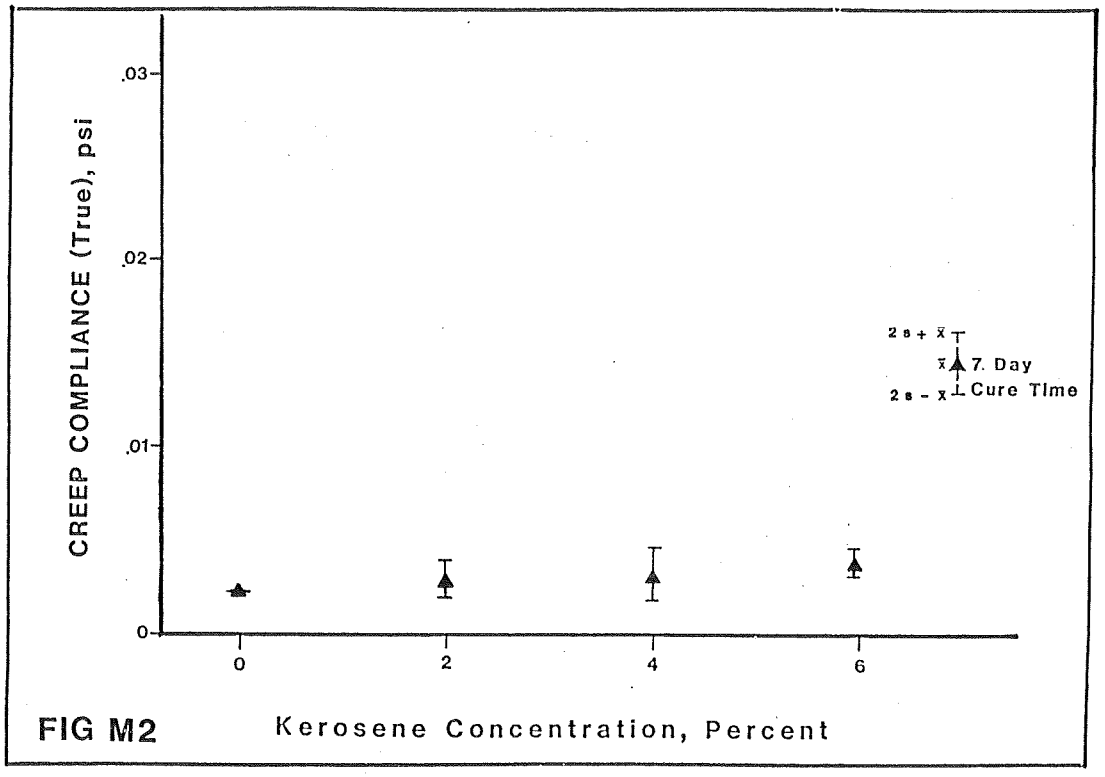
CREEP COMPLIANCE (True), psi
.03
.02
.01
0
0
2
4
6
2s + x̄
x̄
2s - x̄
7. Day
Cure Time
Kerosene Concentration, Percent

FIG M2

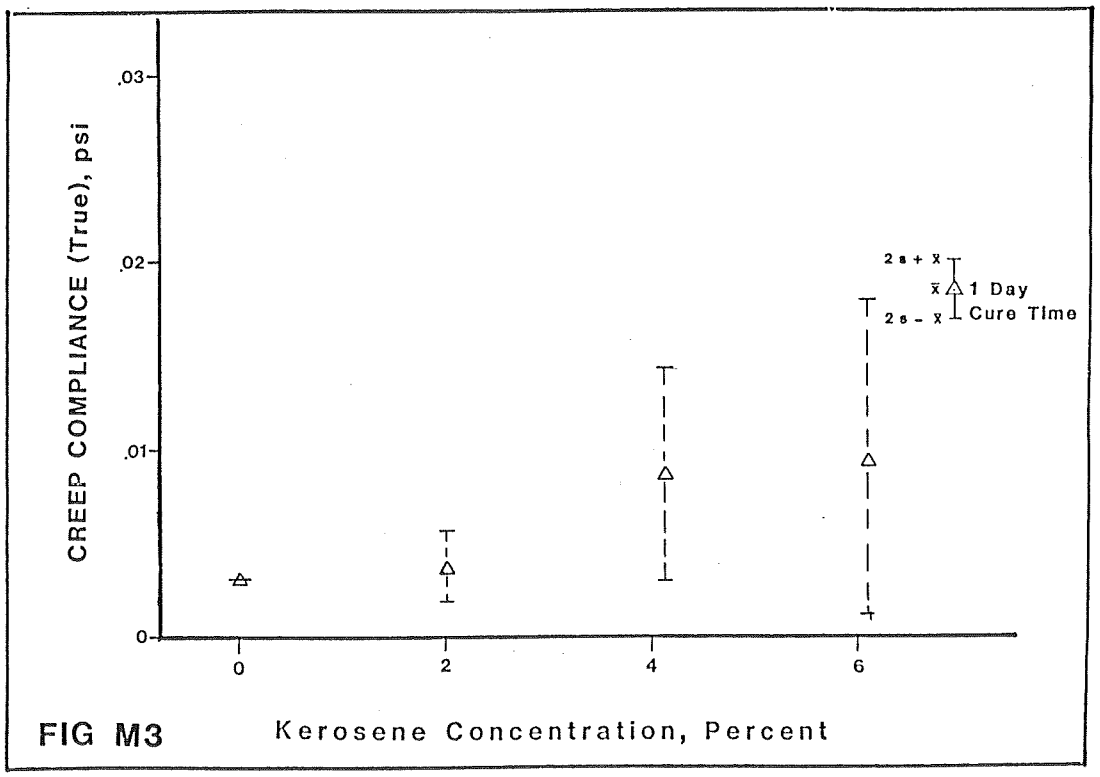
CREEP COMPLIANCE (True), psi
.03
.02
.01
0
0
2
4
6
2s + x̄
x̄
2s - x̄
1 Day
Cure Time
Kerosene Concentration, Percent

FIG M3

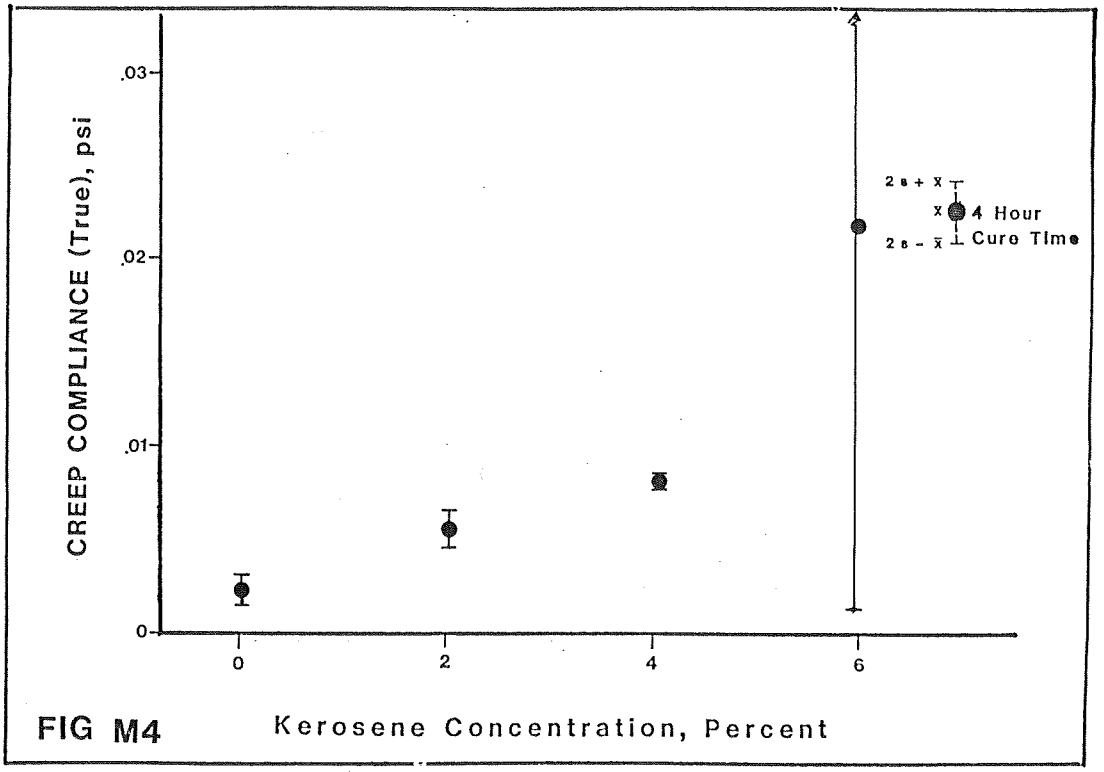
CREEP COMPLIANCE (True), psi
.03
.02
.01
0
0
2
4
6
2s + x̄
x̄
2s - x̄
4 Hour
Cure Time
Kerosene Concentration, Percent

FIG M4

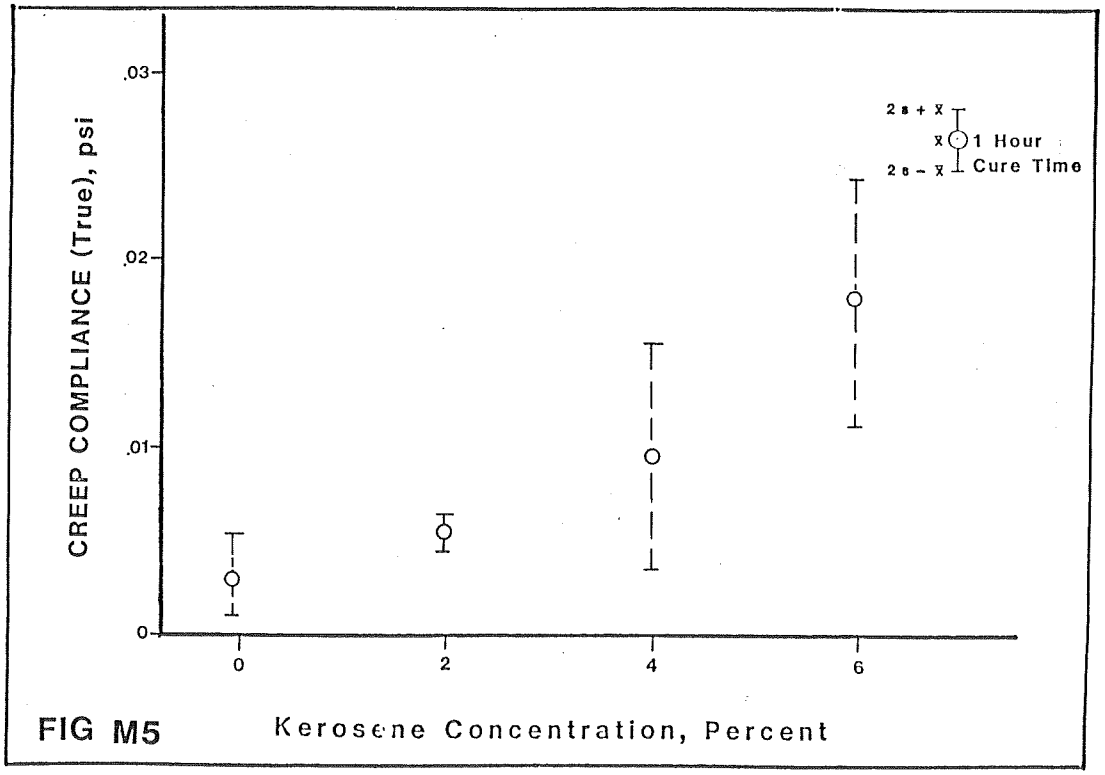
CREEP COMPLIANCE (True), psi
.03
.02
.01
0
0
2
4
6
2s + x̄
x̄
2s - x̄
1 Hour
Cure Time
Kerosene Concentration, Percent

FIG M5

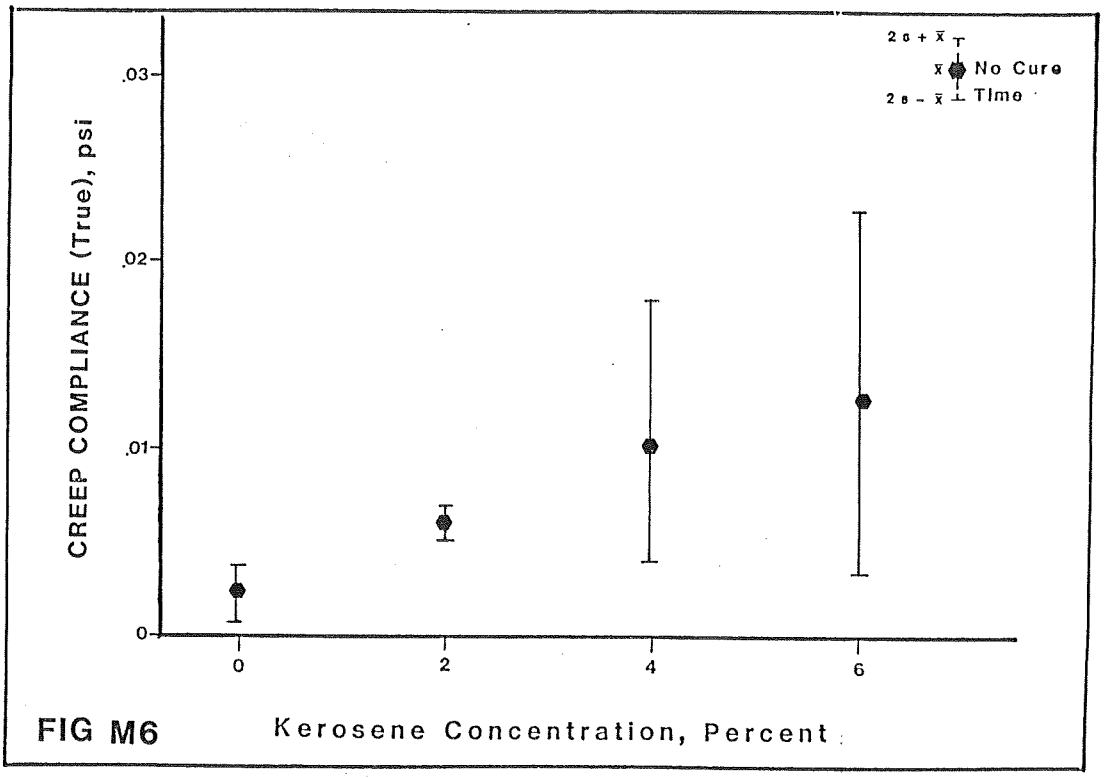
2σ + x̄
x̄ No Cure
2σ − x̄ Time
CREEP COMPLIANCE (True), psi
.03
.02
.01
0
0
2
4
6
Kerosene Concentration, Percent

FIG M6

APPENDIX N

FORCE-DUCTILITY MAXIMUM TRUE CREEP COMPLIANCE AT 39.2F (4C)

Table N-1 Maximum True Creep Compliance, psi^{-1}

a. Calculated Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.0044 .0041 .0039	.00405 .00372 .00338	.00407 .00393 .00389	.0042 .0044 .0039	.00347 .00371 .00388
	.00350 .00314 .00356	.00552 .00402 .00453	.0045 .0044 .0042	.00478 .00437 .00442	.00343 .00312 .00369
2% 410 H	.0087 .0083 .0082	.0076 .0072 .0078	.0076 .0076 .0080	.00554 .00689 .00639	.0047 .0048 .0047
	.00707 .00865 .00829	.00768 .00672 .00616	.0076 .0072 .0064	.00637 .00729 .00659	.00396 .00391 .00398
4% 410 H	.0108 .00877 .0105	.0087 .0105 .00894	.0104 .00911 .0096	.0119 .0112 .0114	.0058 .0057 .0054
	.0147 .0126 .0144	.0135 .0105 .0127	.00982 .00921 .00815	.00825 .00878 .00879	.00479 .00447 .00523
6% 410 H	.01221 .0124 .0129	.0244 .0163 .0126	.0120 .0214 .0158	.01197 .00960 .00889	.00581 .00510 .00525
	.0203 .0156 .0147	.0187 .0223 .0201	.0236 .0317 .0309	.0142 .0136 .0114	.00628 .00558 .00636

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.00377	.00420	.00417	.00435	.00355
	s	.00046	.00075	.00025	.00029	.00027
	cv	12.09	17.83	5.96	6.65	7.56
2% 410 H	$\bar{x}$	.00820	.00718	.00740	.00651	.00434
	s	.00059	.00063	.00051	.00059	.00043
	cv	7.21	8.75	7.45	9.04	9.93
4% 410 H	$\bar{x}$	.01196	.01081	.00938	.01005	.00523
	s	.00235	.00195	.00076	.00161	.00052
	cv	19.61	18.01	8.11	16.04	9.92
6% 410 H	$\bar{x}$	.01469	.01907	.02257	.01161	.00573
	s	.00306	.00423	.00791	.02111	.00052
	cv	20.86	22.20	35.05	18.18	9.09

Table N-2 Maximum True Creep Compliance, psi^{-1}

a. Reduced Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	.00413	.00372	.00396	.00417	.00369
	.00340	.00469	.00437	.00452	.00341
2% 410 H	.00840	.00753	.00773	.00627	.00473
	.00800	.00682	.00707	.00675	.00395
4% 410 H	.01002	.00938	.00970	.01150	.00563
	.01390	.01223	.00906	.00861	.00483
6% 410 H	.01250	.01777	.01640	.01015	.00539
	.01687	.02037	.02873	.01307	.00607

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	.00377	.00421	.00417	.00435	.00355
	s	.00065	.00086	.00036	.00031	.00025
	cv	17.18	20.44	8.72	7.14	6.99
2% 410 H	$\bar{x}$	.00820	.00718	.00740	.00651	.00434
	s	.00035	.00063	.00059	.00043	.00069
	cv	4.32	8.77	7.90	6.53	15.92
4% 410 H	$\bar{x}$	.01196	.01081	.00938	.01006	.00523
	s	.00344	.00253	.00057	.00256	.00071
	cv	28.74	23.37	6.05	25.47	13.55
6% 410 H	$\bar{x}$	.01469	.01907	.02257	.01161	.00573
	s	.00387	.00230	.01092	.00259	.00060
	cv	26.37	12.08	48.41	22.28	10.51

Table N-3 Log Maximum True Creep Compliance, psi^{-1}

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	-2.38405	-2.42946	-2.40231	-2.37986	-2.43297
	-2.46852	-2.32883	-2.35952	-2.34486	-2.46725
2% 410 H	-2.07572	-2.13231	-2.11182	-2.20273	-2.32514
	-2.09691	-2.16622	-2.15058	-2.17070	-2.40340
4% 410 H	-1.99913	-2.02780	-2.01323	-1.93930	-2.24949
	-1.85699	-1.91257	-2.04287	-2.06500	-2.31605
6% 410 H	-1.90309	-1.75031	-1.78516	-1.99353	-2.26841
	-1.77289	-1.69101	-1.54166	-1.88372	-2.21681

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	-2.42629	-2.37914	-2.38091	-2.36236	-2.45011
	s	.07484	.08916	.03791	.03101	.03037
	cv	3.09	3.75	1.59	1.31	1.24
2% 410 H	$\bar{x}$	-2.08632	-2.14471	-2.13120	-2.18671	-2.36427
	s	.01877	.03811	.03434	.02838	.06934
	cv	.90	1.78	1.61	1.30	2.93
4% 410 H	$\bar{x}$	-1.92806	-1.97019	-2.02805	-2.00215	-2.28277
	s	.12594	.10209	.02626	.11137	.05897
	cv	6.53	5.18	1.30	5.56	2.58
6% 410 H	$\bar{x}$	-1.83799	-1.72066	-1.66341	-1.93863	-2.24261
	s	.11536	.05254	.21573	.09729	.04572
	cv	6.28	3.05	12.97	5.02	2.04

Table N-4 ANOVA Summary, Log Maximum True Creep Compliance

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	1.453	.4845	106.77	3.10	4.94
Tj	4	.4617	.1154	25.43	2.87	4.43
(CT)ij	12	.2156	.01796	3.96	2.28	3.23
Error	20	.09076	.004537			
TOTAL	39					

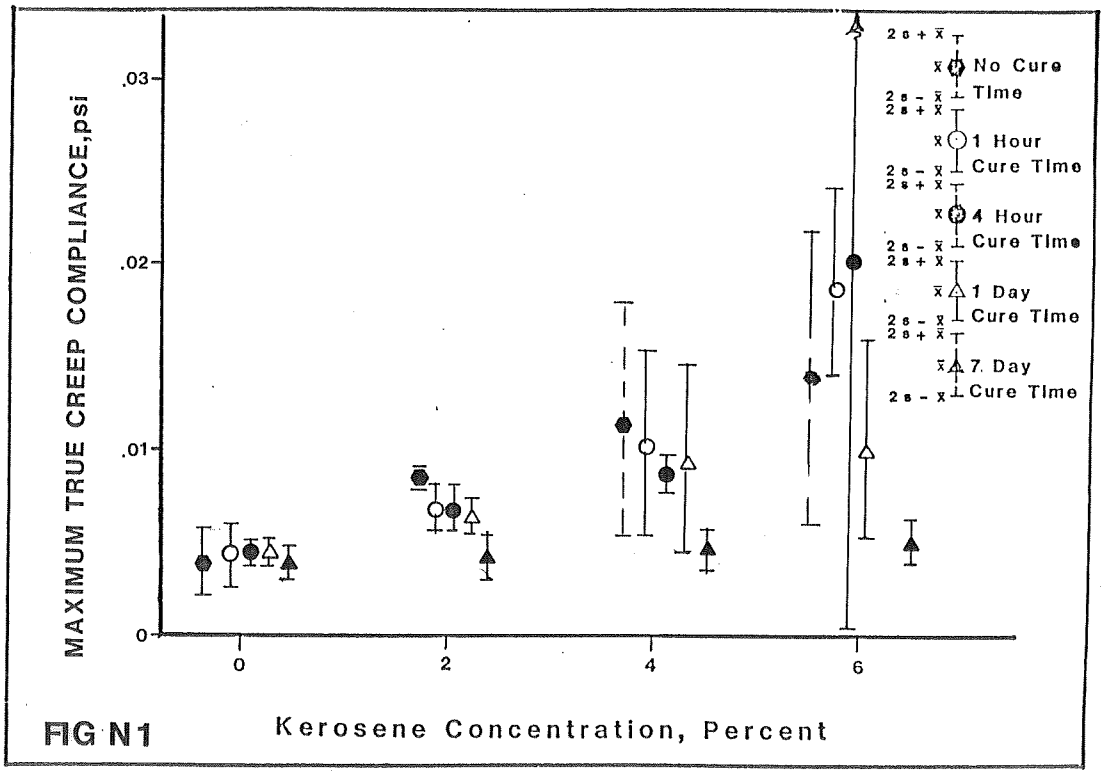

FIG N1

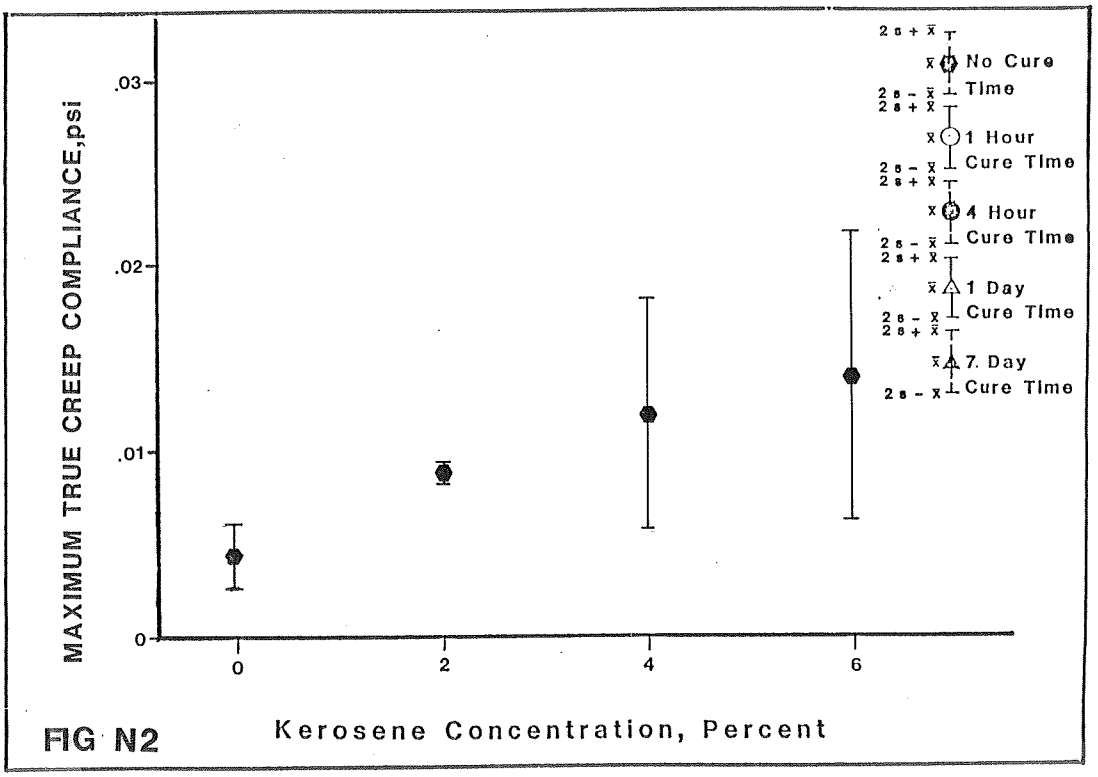
MAXIMUM TRUE CREEP COMPLIANCE,psi
.03
.02
.01
0
0
2
4
6
No Cure Time
1 Hour Cure Time
4 Hour Cure Time
1 Day Cure Time
7 Day Cure Time
Kerosene Concentration, Percent

FIG N2

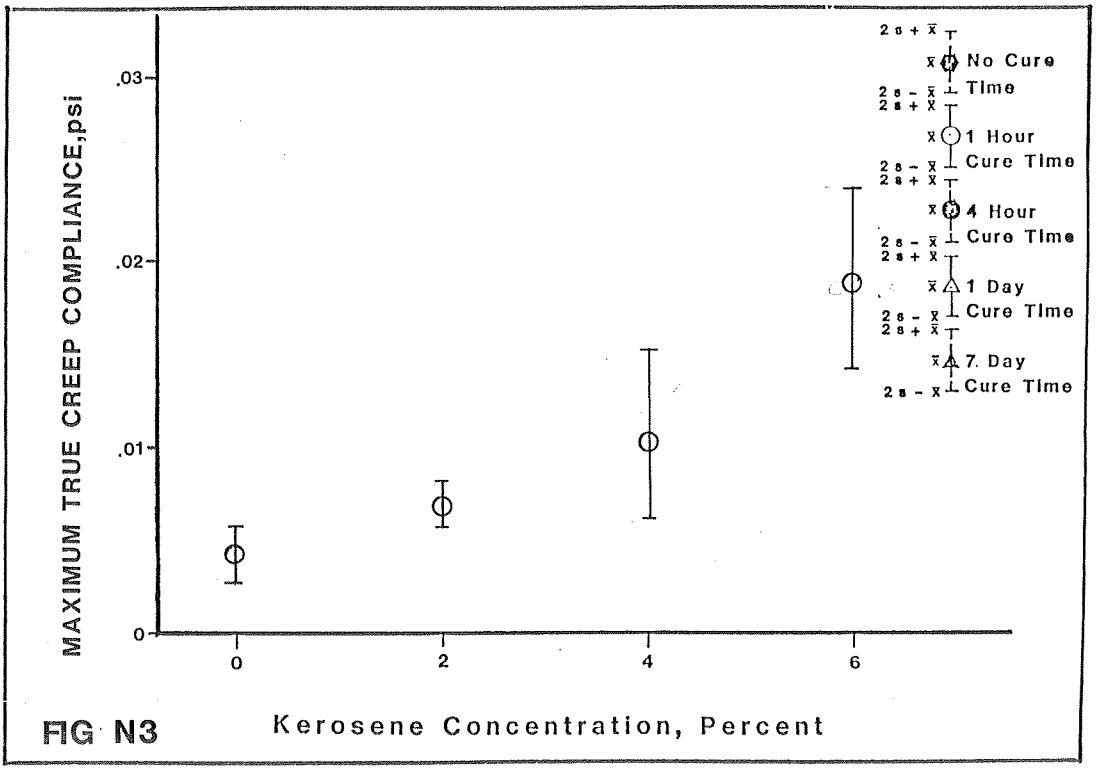
MAXIMUM TRUE CREEP COMPLIANCE,psi
.03
.02
.01
0
0
2
4
6
No Cure Time
1 Hour Cure Time
4 Hour Cure Time
1 Day Cure Time
7 Day Cure Time
Kerosene Concentration, Percent

FIG N3

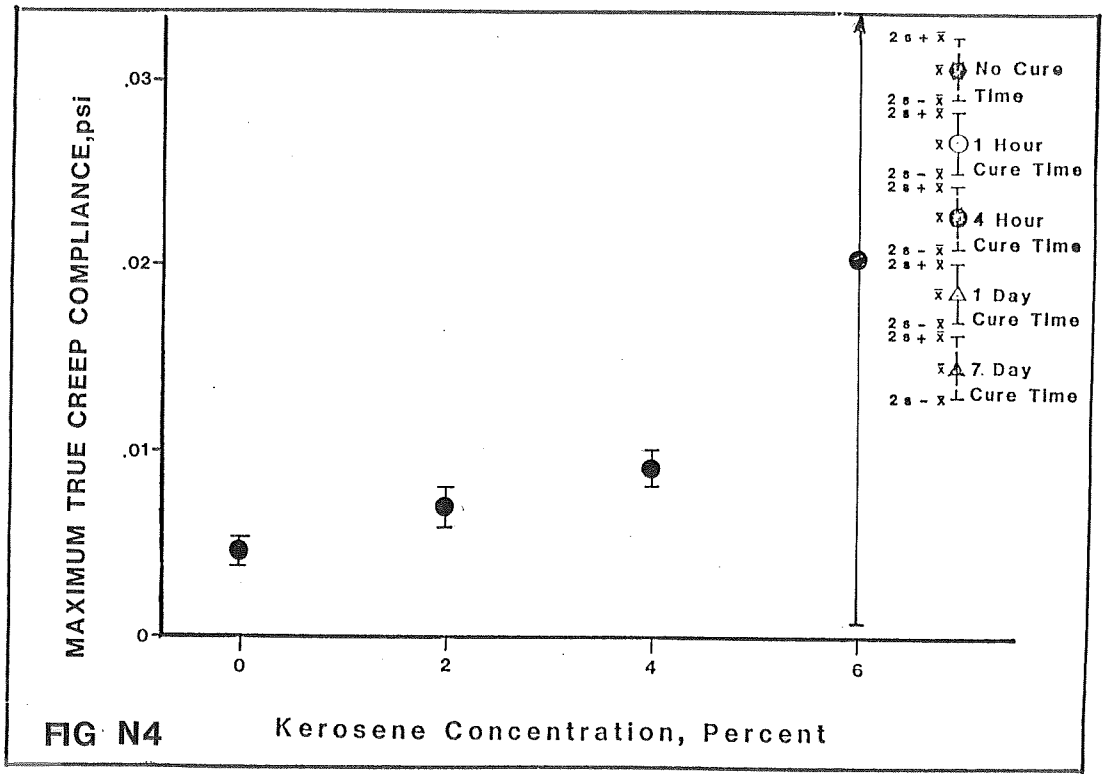
MAXIMUM TRUE CREEP COMPLIANCE,psi
.03
.02
.01
0
0
2
4
6
No Cure Time
1 Hour Cure Time
4 Hour Cure Time
1 Day Cure Time
7. Day Cure Time
Kerosene Concentration, Percent

FIG N4

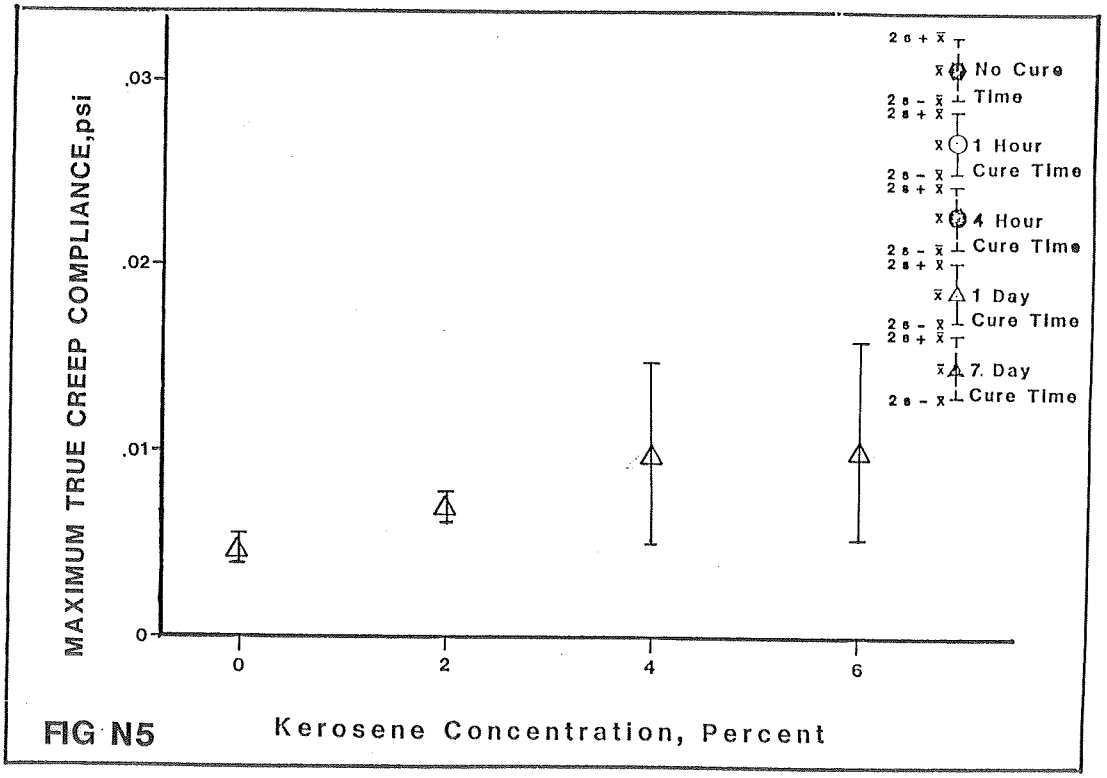
MAXIMUM TRUE CREEP COMPLIANCE,psi
.03
.02
.01
0
0
2
4
6
No Cure Time
1 Hour Cure Time
4 Hour Cure Time
1 Day Cure Time
7. Day Cure Time
Kerosene Concentration, Percent

FIG N5

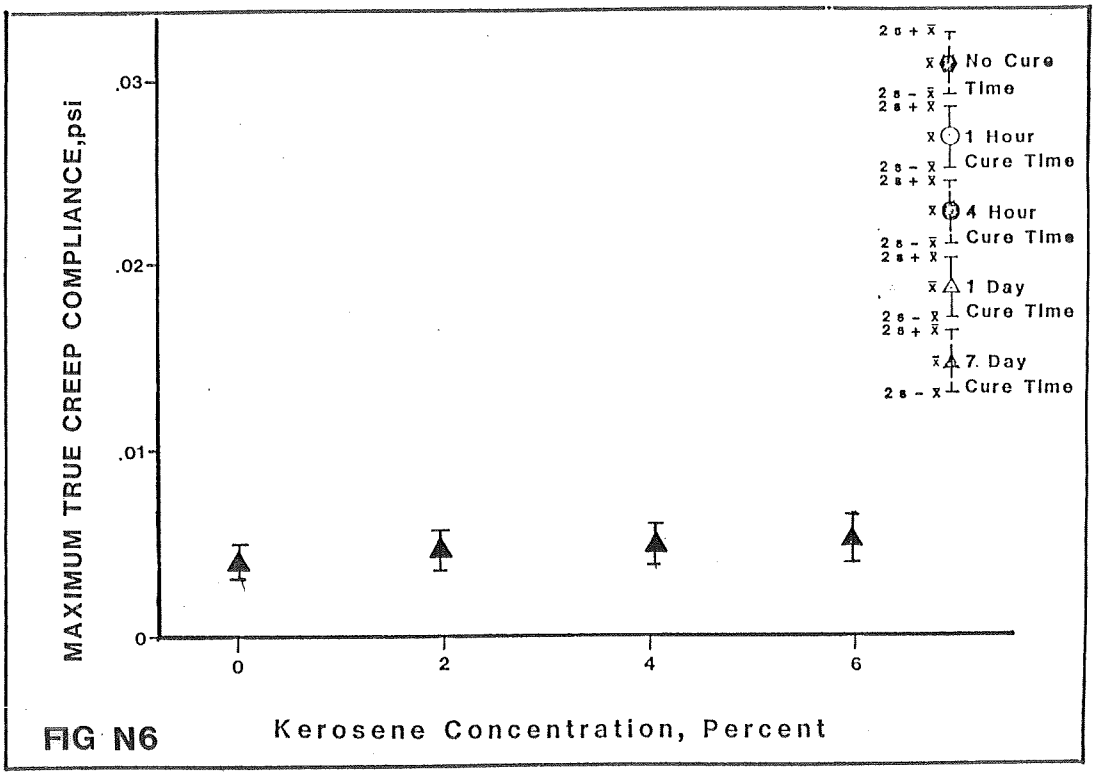
MAXIMUM TRUE CREEP COMPLIANCE,psi
.03
.02
.01
0
0
2
4
6
Kerosene Concentration, Percent
No Cure Time
1 Hour Cure Time
4 Hour Cure Time
1 Day Cure Time
7 Day Cure Time

FIG N6

APPENDIX O

FORCE DUCTILITY TIME TO MAXIMUM TRUE CREEP COMPLIANCE AT 39.2F(4C)

Table O-1 Time to Maximum True Creep Compliance, Minutes

a. Measured Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	7 8 8	9 9 10	9 8 10	7 9 9	10 8 8
	8 10 8	7 8 7	9 8 8	8 8 8	8 8 10
2% 410 H	6 6 6	7 7 7	10 8 6	8 8 8	7 8 7
	10 10 10	10 8 8	8 7 8	8 8 7	8 8 8
4% 410 H	9 8 11	6 12 9	8 8 8	10 10 11	9 8 9
	20 19 21	17 8 18	10 8 8	8 12 8	8 8 8
6% 410 H	10 8 8	26 20 12	24 22 22	7 8 8	9 8 8
	14 12 10	24 20 16	18 20 16	14 12 10	9 8 8

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	8.2	8.3	8.7	8.2	8.7
	s	.983	1.211	.817	.753	1.033
	cv	12.04	14.53	9.42	9.22	11.92
2% 410 H	$\bar{x}$	8.0	7.8	7.8	7.8	7.7
	s	2.191	1.169	1.329	.408	.516
	cv	27.39	14.93	16.97	5.21	6.74
4% 410 H	$\bar{x}$	14.7	11.7	8.3	9.8	8.3
	s	5.955	4.926	.817	1.602	.516
	cv	40.61	42.22	9.80	16.29	6.20
6% 410 H	$\bar{x}$	10.3	19.7	20.3	9.8	8.3
	s	2.338	5.125	2.944	2.714	.516
	cv	22.63	26.06	14.48	27.60	6.20

Table O-2 Time to Maximum True Creep Compliance, Minutes

a. Analyzed Data

	0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	7.7 / 8.7	9.3 / 7.3	9.0 / 8.3	8.3 / 8.0	8.7 / 8.7
2% 410 H	6.0 / 10.0	7.0 / 8.7	8.0 / 7.7	8.0 / 7.7	7.3 / 8.0
4% 410 H	9.3 / 20.0	9.0 / 14.3	8.0 / 8.7	10.3 / 9.3	8.7 / 8.0
6% 410 H	8.7 / 12.0	19.3 / 20.0	22.7 / 18.0	7.7 / 12.0	8.3 / 8.3

b. Summary

		0	1 hr.	4 hr.	24 hr.	168 hr.
0% 410 H	$\bar{x}$	8.20	8.30	8.65	8.15	8.7
	s	.886	1.772	.620	.266	0
	cv	10.81	21.35	7.17	3.26	0
2% 410 H	$\bar{x}$	8.00	7.85	7.85	7.85	7.65
	s	3.544	1.506	.266	.266	.620
	cv	44.30	19.19	3.39	3.39	8.11
4% 410 H	$\bar{x}$	14.65	11.65	8.35	9.80	8.35
	s	9.480	4.696	.620	.866	.620
	cv	64.71	40.31	7.43	9.04	7.43
6% 410 H	$\bar{x}$	10.35	19.65	20.35	9.85	8.30
	s	2.924	.620	4.164	3.810	0
	cv	28.25	3.16	20.46	38.68	0

Table O-3 ANOVA Summary, Time to Maximum True Creep Compliance

ANOVA

Source	df	SS	MS	F	F.05	F.01
Ci	3	211.67	70.56	12.73	3.10	4.94
Tj	4	75.33	18.83	3.40	2.87	4.43
(CT)ij	12	251.51	20.96	3.78	2.28	3.23
Error	20	110.83	5.54			
TOTAL	39	649.33				

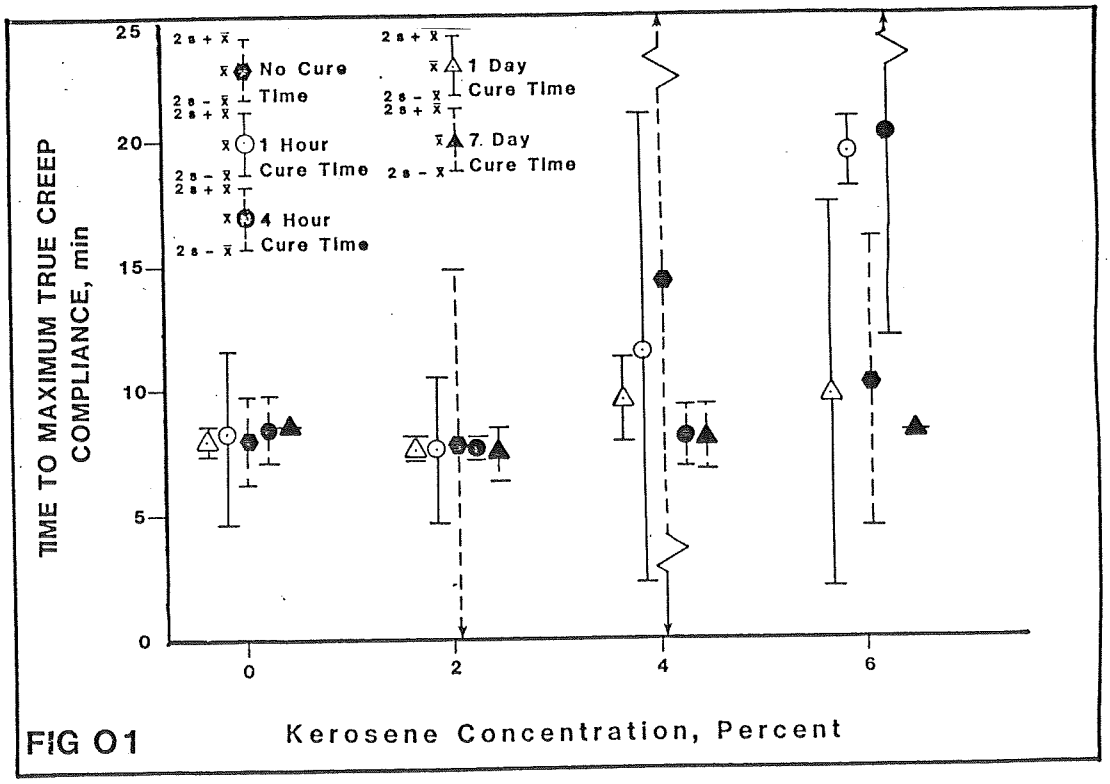

FIG O1

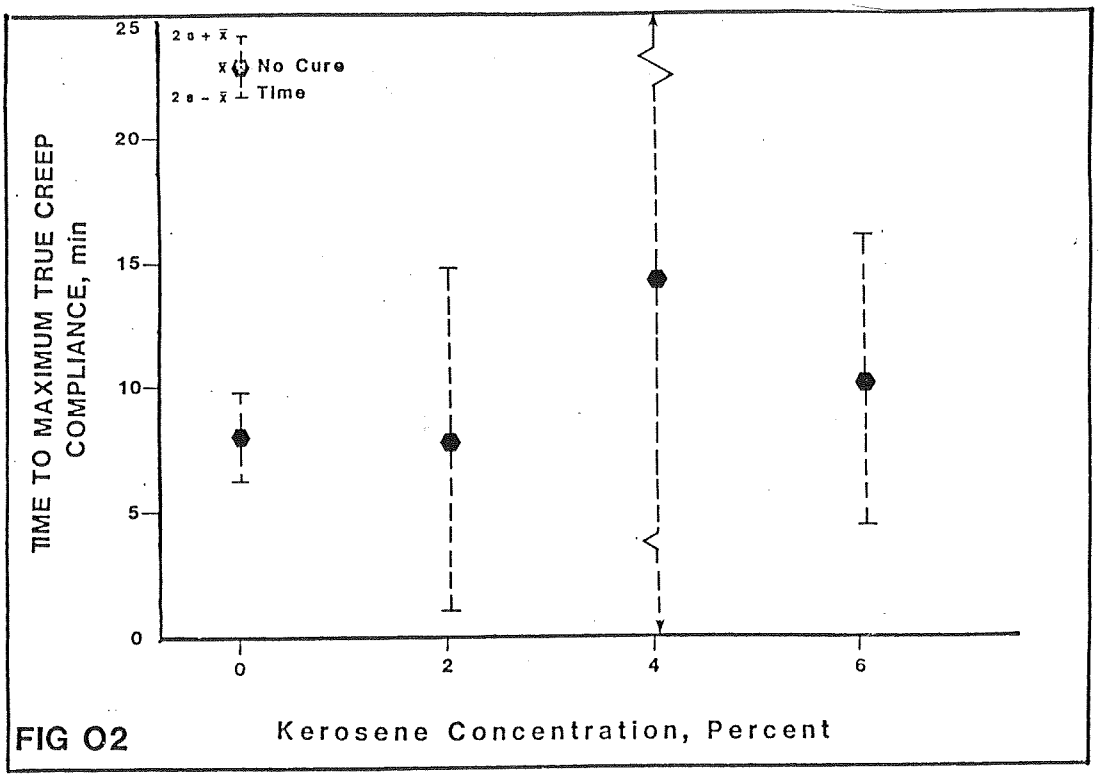
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
2σ + x̄
x̄
2σ − x̄
No Cure
Time
0
2
4
6
Kerosene Concentration, Percent

FIG O2

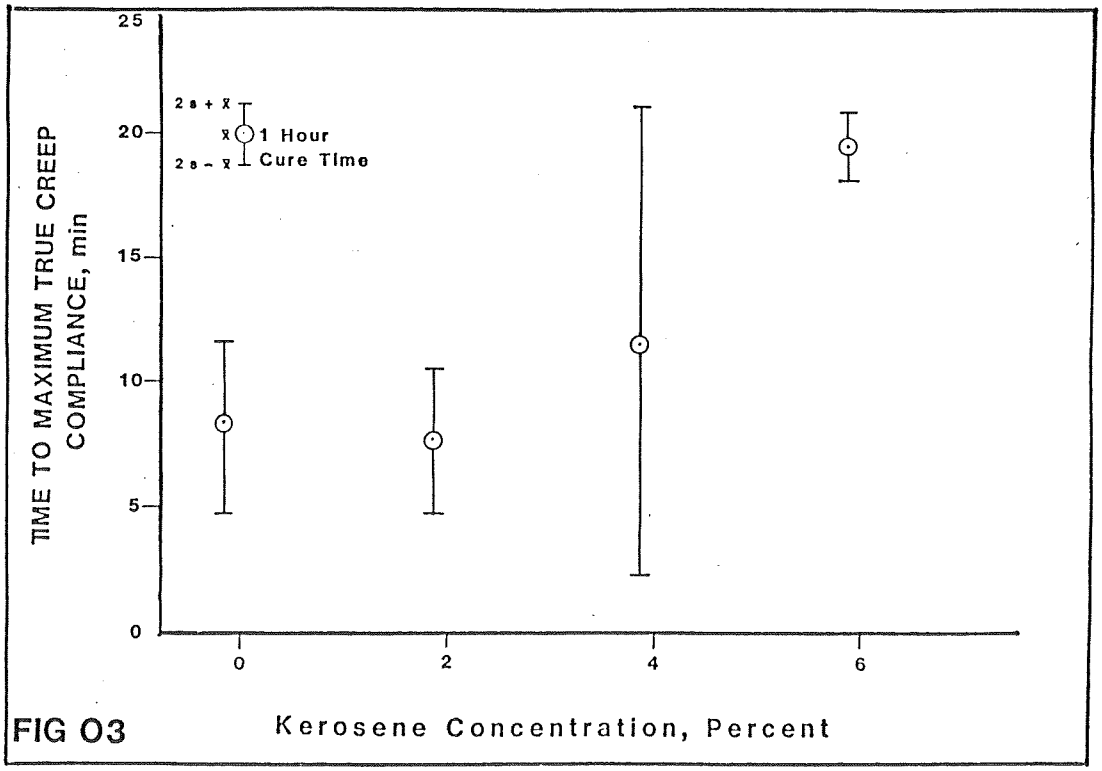
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
2σ + x̄
x̄
2σ − x̄
1 Hour
Cure Time
0
2
4
6
Kerosene Concentration, Percent

FIG O3

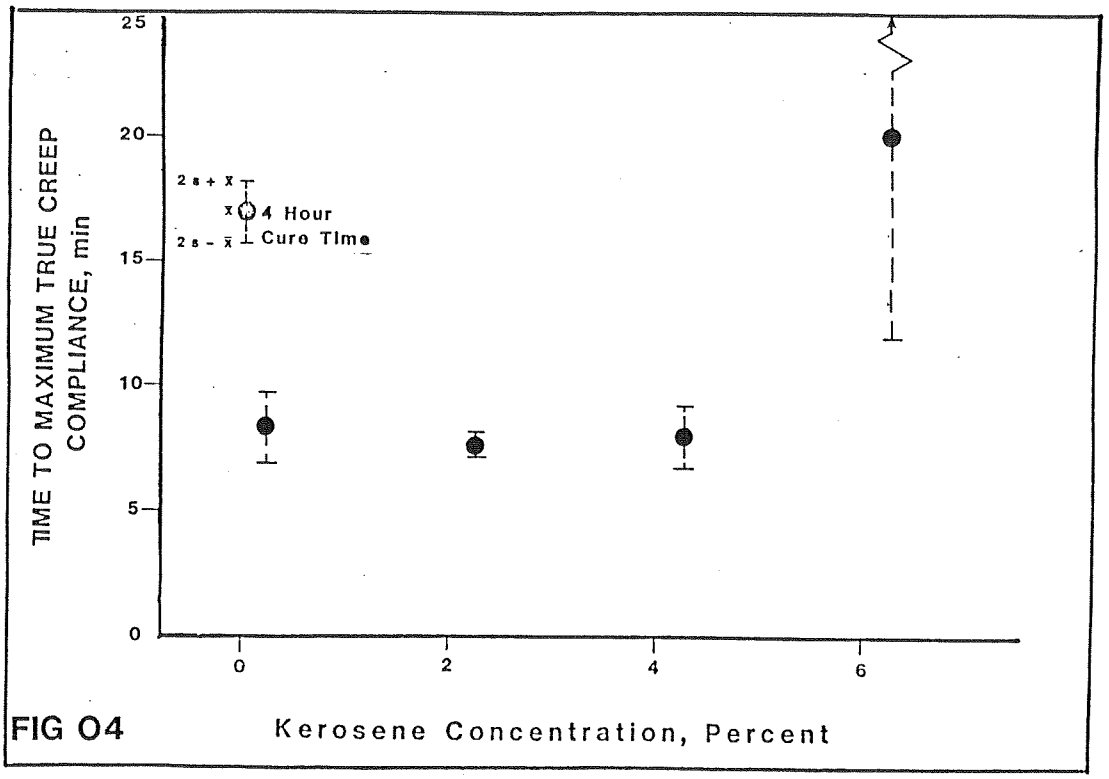
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
2 s + x̄
x̄
4 Hour
2 s - x̄
Cure Time
0
2
4
6
Kerosene Concentration, Percent

FIG 04

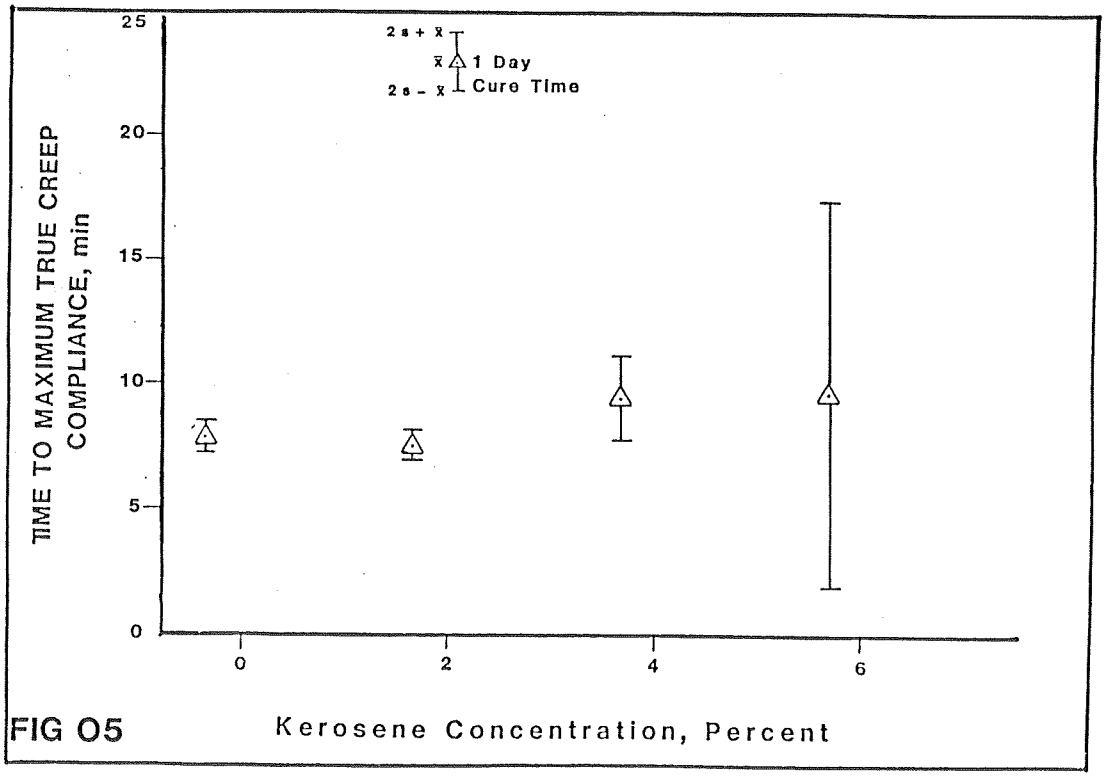
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
2 s + x̄
x̄
1 Day
2 s - x̄
Cure Time
0
2
4
6
Kerosene Concentration, Percent

FIG 05

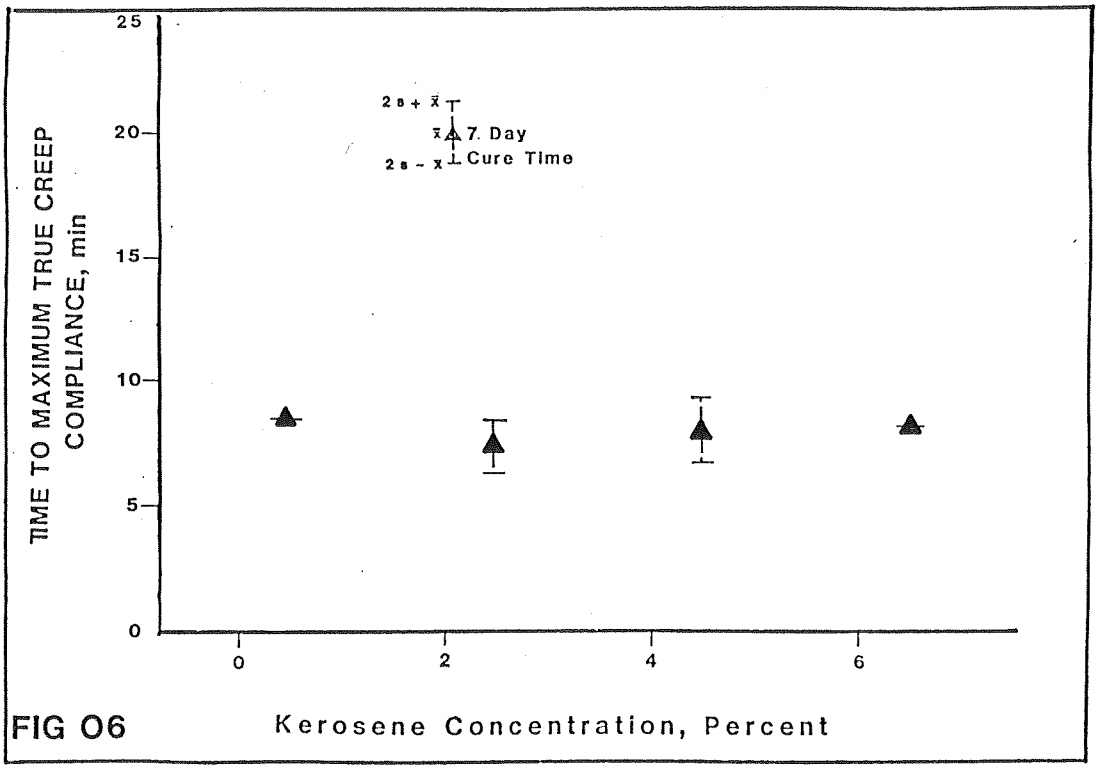
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
2s + x̄
x̄
2s - x
7 Day
Cure Time
0
2
4
6
Kerosene Concentration, Percent

FIG 06

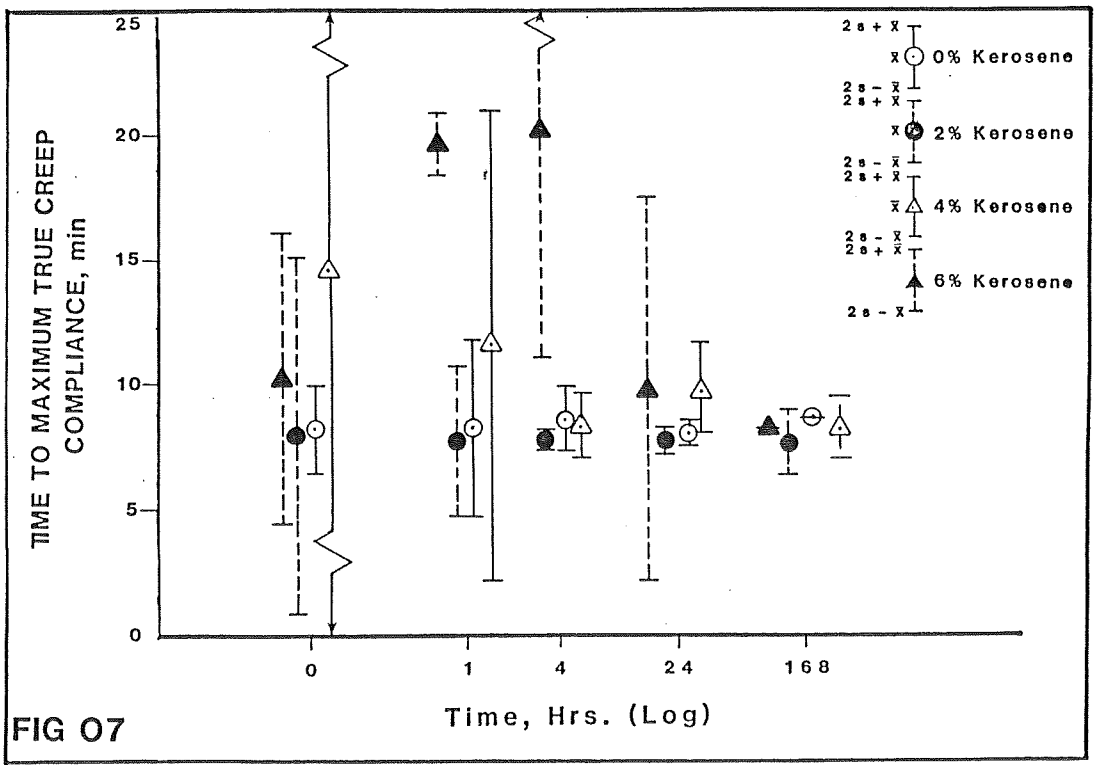
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
2s + x̄
x̄
0% Kerosene
2s - x̄
2s + x̄
2% Kerosene
2s - x̄
2s + x̄
4% Kerosene
2s - x̄
2s + x̄
6% Kerosene
2s - x̄
0
1
4
24
168
Time, Hrs. (Log)

FIG 07

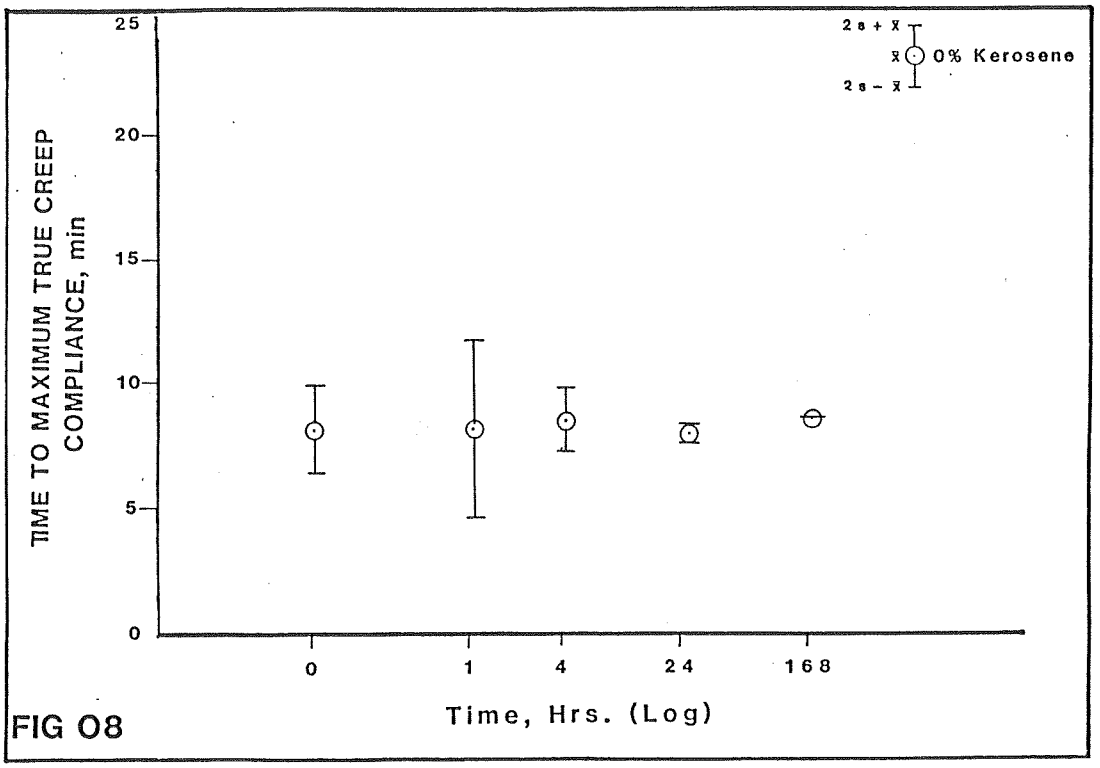
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
0
1
4
24
168
Time, Hrs. (Log)
2s + x̄
x̄
2s − x̄
0% Kerosene

FIG 08

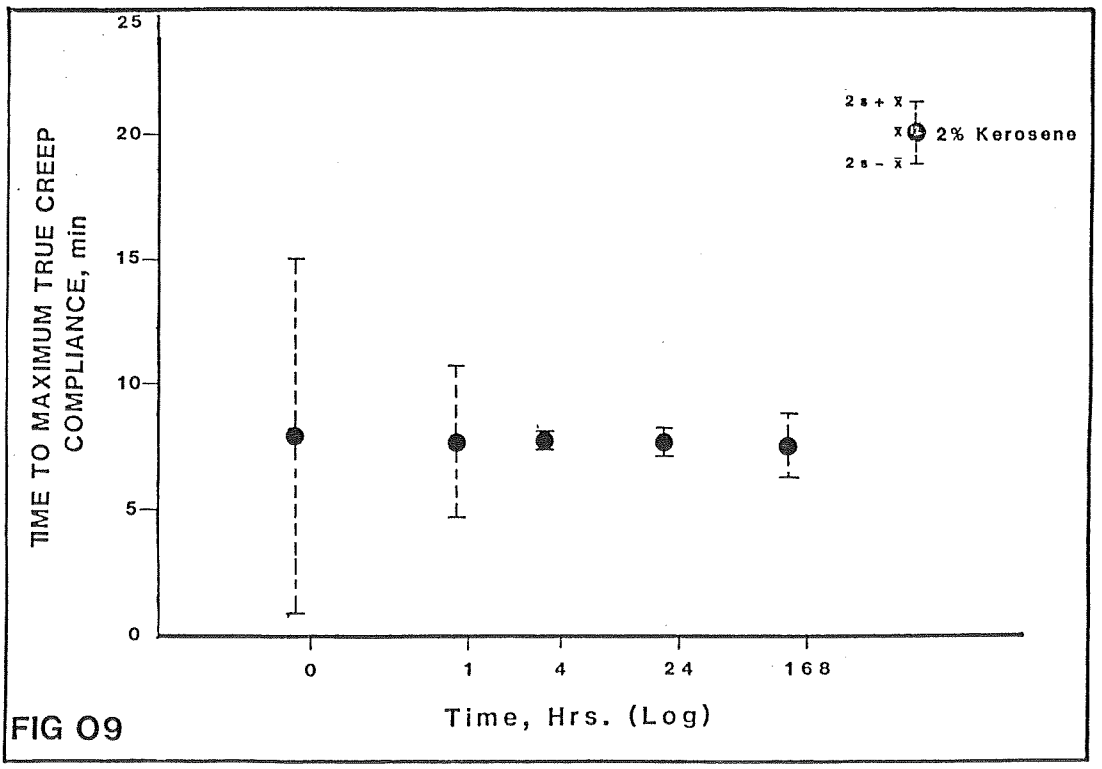
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, min
25
20
15
10
5
0
0
1
4
24
168
Time, Hrs. (Log)
2s + x̄
x̄
2s − x̄
2% Kerosene

FIG 09

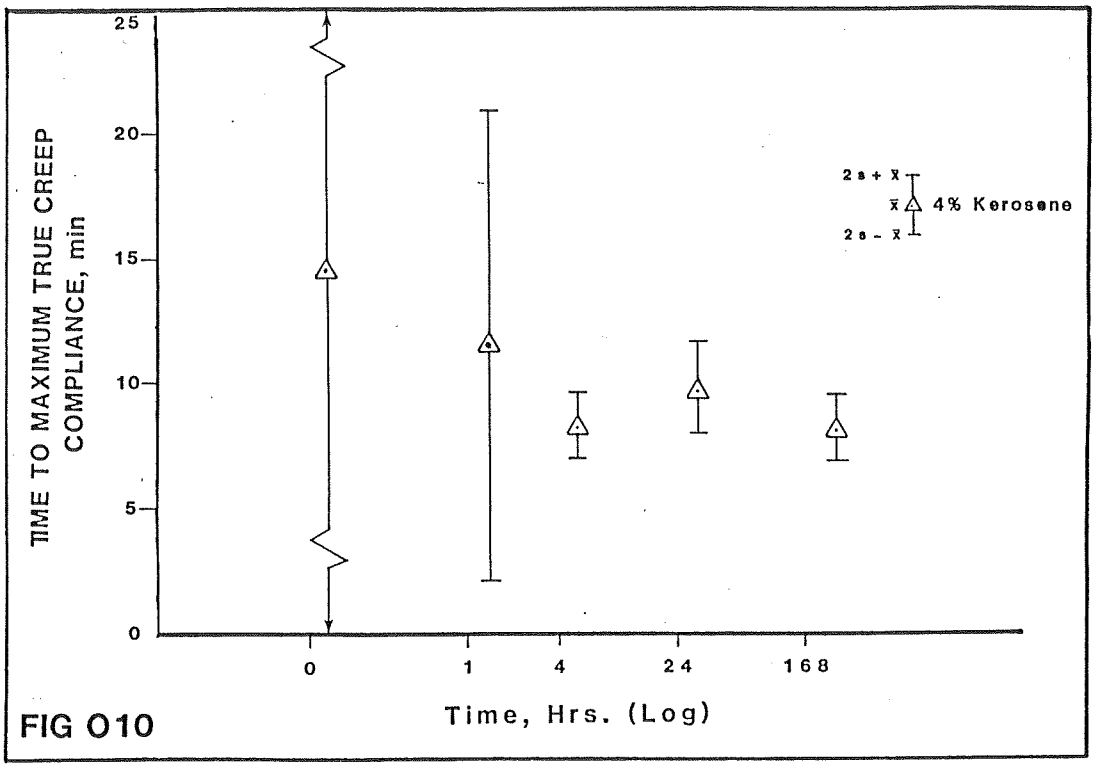

FIG O10

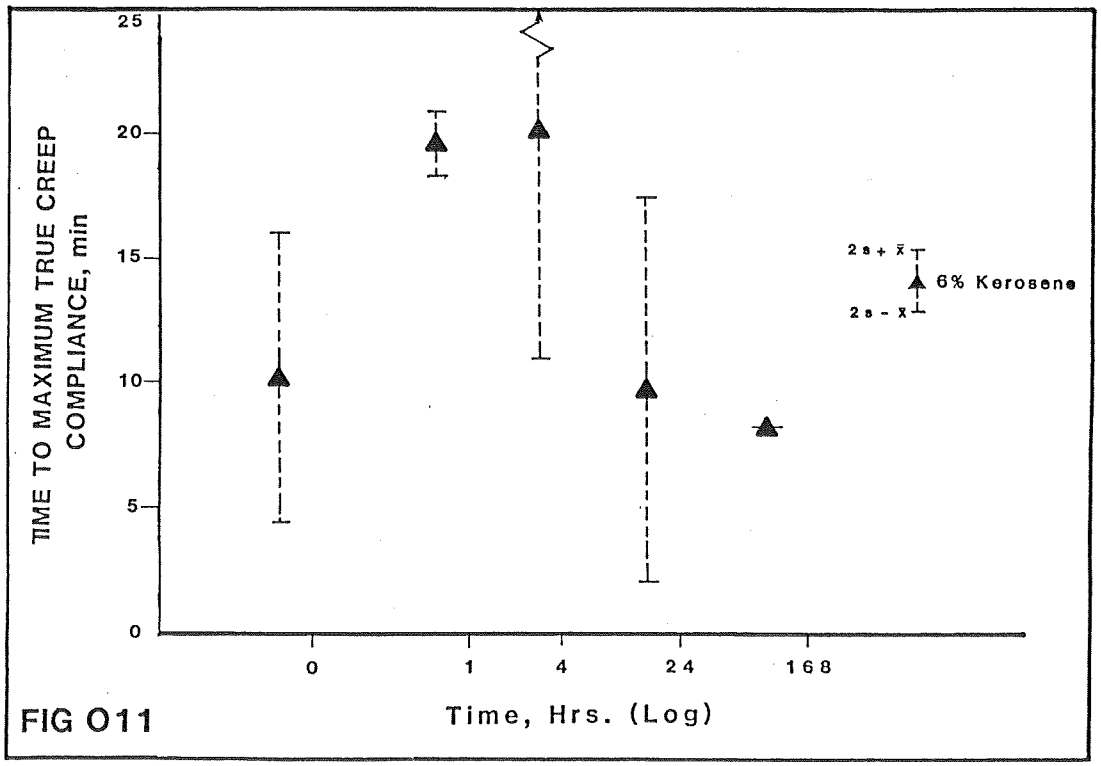

FIG O11

APPENDIX P

TORQUE-FORK VISCOSITY DURING MIXING AT 375F (191C) AND 500 RPM, POISES

Table P-1 Drop in Torque-Fork Viscosity at 375F (191C) and 500 RPM on Addition of Diluent, Poise

	2%	4%	6%
DATA	1.4 2.9 2.9 1.4 1.4	4.3 5.1 5.8 3.6 5.1	5.8 7.3 5.8 5.1 7.3
$\bar{x}$	2.00	4.78	6.26
s	0.88	0.85	0.99
cv	41.1	17.7	15.8

Table P-2 One-Way ANOVA Summary, Drop In Torque-Fork Viscosity

ANOVA

Source	df	SS	MS	F	F.05	F.01
Diluent	2	46.78	23.39	29.54	3.89	6.93
Error	12	9.50	0.79			
TOTAL	14	56.28				

Table P-3 Torque-Fork Viscosity after 1 Hour of Mixing at 375F (191C) and 500 RPM, Poise

		0%	2%	4%	6%
1 Hr.	DATA	44.9 34.5 37.4 37.4 36.0	33.1 34.5 37.4 34.5 36.0	36.1 36.0 36.0 34.5 37.4	33.1 36.0 31.7 20.3 28.9
	$\bar{x}$	38.0	35.1	36.0	32.0
	s	4.0	1.6	1.0	2.7
	cv	10.6	4.7	2.9	8.5

Table P-4 One-Way ANOVA Summary, Torque-Fork Viscosity at 1 Hour

ANOVA

Source	df	SS	MS	F	F.05	F.01
Diluent	3	175.33	58.44	4.19	3.25	5.32
Error	16	223.41	13.96			
TOTAL	19	398.75				

APPENDIX Q

HAAKE VISCOSITY DURING MIXING AT 375F (191C), POISES

Table Q-1 Haake Viscosity After 1 hour of Mixing at 375F (191C), Poise

		0%	2%	4%	6%
1 Hr.	DATA	-*	30	45	50
		40	37	35	50
		30	30	35	43
		35	35	30	-*
		-*	30	30	30
	$\bar{x}$	35.0	32.4	35.0	43.3
	s	5.0	3.4	6.1	9.4
	cv	14.3	10.4	17.5	21.8

*Note: Reading not obtained

Table Q-2 One-Way ANOVA Summary, Haake Viscosity at 1 Hour

ANOVA

Source	df	SS	MS	F	F.05	F.01
Diluent	3	282.52	94.17	2.39	3.40	5.80
Error	13	511.95	39.38			
TOTAL	16	794.47				