ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA/AZ-82/159/5

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

## VOLUME 5

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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 | 5. Report Date |
|---|---|
| Chemical and Physical Properties of Asphalt-Rubber Mixtures - Phase III, Volume V - Effect of Temperature | 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 temperature on physical properties of asphalt-rubber mixtures. Eight different asphalt-rubber mixtures formulated with two different asphalts and two types of granulated reclaimed rubber at 20 and 25 percent concentrations were studied. These mixtures were comparable to mixtures supplied by two of the major asphalt-rubber producers. These mixtures were tested at three different temperatures - 77F (25C), 39.2F (4C), and -20F (-29C).

Asphalt-rubber mixtures were produced in the Torque-Fork mixer at 375F using a one hour mixing duration. Testing procedures utilized were the Schweyer Rheometer and Force-Ductility. A total of 12 measured or calculated parameters are reported and discussed.

The study concluded that (1) temperature significantly influences physical properties of asphalt-rubber mixtures, (2) that mixtures made with the two rubber types and asphalts studied behave differently at different temperatures.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Asphalt-rubber, asphalt, viscosity, force-ductility, Schweyer Rheometer, stress, Torque-Fork, Temperature Susceptibility | 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 | 86 | |

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 temperature on physical properties of asphalt-rubber mixtures.

1.2 A laboratory investigation was performed which considered asphalt-rubber mixtures formulated with two rubber types, two rubber concentrations and two asphalts. Testing was performed at three different temperatures.

1.2.1 Granulated rubber utilized was produced from two different reclamation processes and materials as follows:

- Ambient grind tread peel crumb (Atlos TPO44)
- Ambient grind high natural rubber content devulcanized crumb (U.S. Rubber Reclaiming GT274)

Each of the two rubber types studied was incorporated into asphalt-rubber mixtures at two concentrations - 20 and 25 percent by weight of total mixture.

1.2.2 The two asphalt types utilized were:

- ARCO AR4000 with 2 percent Califlux GP extender oil
- Sahuaro AR1000

1.2.3 Properties and characteristics of the asphalts and rubbers are contained in the project Summary Report (1).

1.2.4 Testing temperatures were 77F (25C), 39.2F (4C) and -20F (-29C).

1.2.5 Asphalt-rubber mixtures were all prepared using a standard mixing procedure in the Arizona Torque-Fork as described in the project Summary Report (1).

1.3 Materials properties assessed in this study are:

- Apparent viscosity and shear rate sensitivity by the Schweyer Rheometer
- Stress, strain, and creep compliance properties using Force-Ductility

1.3.1 A total of 12 different parameters were evaluated, analyzed and reported. Details of testing procedures and calculations are contained in the project Summary Report (1).

## 2.0 EXPERIMENTAL DESIGN AND DATA ANALYSIS

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

2.1.1 The experimental matrix is presented in Figure 1.

2.1.2 This experiment utilized portions of data reported in Volume I, "Effects of Rubber Type, Concentration, and Asphalt" of this investigation. Data utilized from Volume I was at 39.2F (4C) for the mixtures investigated. Testing sequence at 77F (25C) and -20F (-29C) was sequentially randomized - first by temperature and then by mixture type.

2.1.3 The fixed factor model is:

$$Y_{ijklm} = \mu + R_i + Q_j + A_k + T_l + (RQ)_{ij} + (RA)_{ik} + (RT)_{il} + (QA)_{jk} + (QT)_{jl} + (AT)_{kl} + (RQA)_{ijk} + (RAT)_{ikl} + (QAT)_{jkl} + (RQT)_{ijl} + (RQAT)_{ijkl} + \varepsilon_{(ijkl)m}$$

in which:

$Y_{ijklm}$ = Response variable (Schweyer constants, true stress, etc.) for the $i^{th}$ level of rubber type, $j^{th}$ level of rubber concentration, $k^{th}$ level of asphalt, $l^{th}$ level of temperature, and $m^{th}$ replication.

$\mu$ = Effect of overall mean

$R_i$ = Effect of rubber type

$Q_j$ = Effect of rubber concentration

$A_k$ = Effect of asphalt type

$T_l$ = Effect of temperature

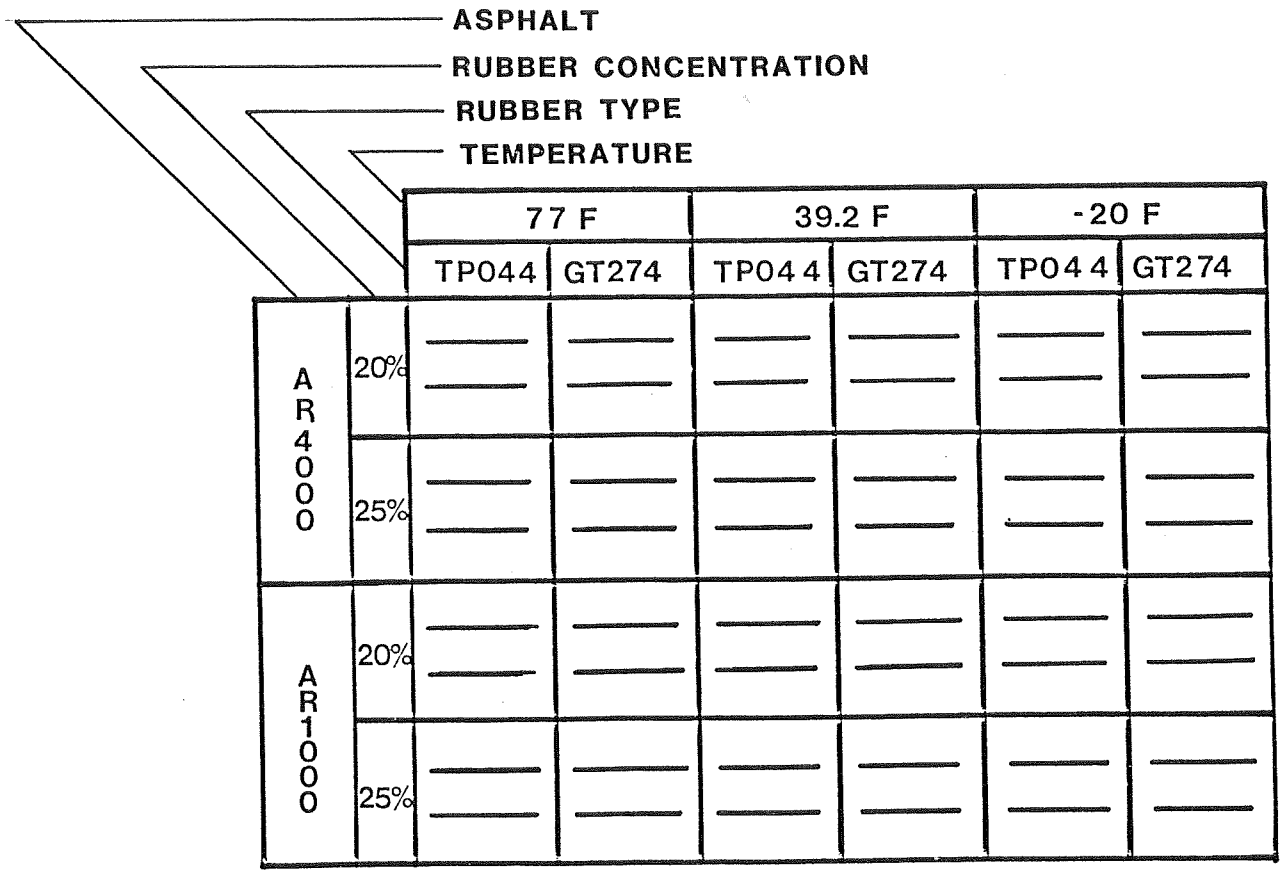


Figure 1 Experiment Test Matrix

$(RQ)_{ij}$, $(RA)_{ik}$, $(RT)_{il}$, $(QA)_{jk}$, $(QT)_{jl}$, $(AT)_{kl}$ = Second order interactions

$(RQA)_{ijk}$, $(RAT)_{ikl}$, $(QAT)_{jkl}$, $(RQT)_{ijl}$ = Third order interactions

$(RQAT)_{ijkl}$ = Fourth order interaction

$\varepsilon_{(ijkl)m}$ = Experimental error

2.1.4 Degrees of freedom for the analysis are as follows:

| Source | Degrees of Freedom |
|---|---|
| $R_i$ | 1 |
| $Q_j$ | 1 |
| $A_k$ | 1 |
| $T_l$ | 2 |
| $(RQ)_{ij}$ | 1 |
| $(RA)_{ik}$ | 1 |
| $(RT)_{il}$ | 2 |
| $(QA)_{jk}$ | 1 |
| $(QT)_{jl}$ | 2 |
| $(AT)_{kl}$ | 2 |
| $(RQA)_{ijk}$ | 1 |
| $(RAT)_{ikl}$ | 2 |
| $(QAT)_{jkl}$ | 2 |
| $(RQT)_{ijl}$ | 2 |
| $(RQAT)_{ijkl}$ | 2 |
| Error | 24 |
| Total | 47 |

2.1.5 Prior to analysis, homogeneity of variance was tested by the Foster and Burr q-test (2). Appropriate data transformations were used when necessary to comply with variance homogeneity constraints required for analysis of variance.

## 2.2 Levels of Independent Variables

### 2.2.1 Rubber at two levels:

- TP044
- GT274

### 2.2.2 Rubber quantities at two levels, 20 and 25 percent by weight of the asphalt-rubber mixture.

### 2.2.3 Asphalt at two levels:

- AR4000 + 2 percent extender oil
- AR1000

### 2.2.4 Temperature at three levels:

- 77F (25C)
- 39.2F (4C)
- -20F (-29C)

## 3.0 RESULTS AND DISCUSSIONS

### 3.1 Schweyer Rheometer Constant, F-tube.

3.1.1 Measured rheometer constants using the F-tube are tabulated in Appendix A in Table A-1 and plotted in Figures A1 and A2.

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

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

3.1.3.1 Rubber type is a significant effect at the 0.05 level but not at the 0.01. Temperature is significant at the 0.01 level. All other main effects and interactions are not significant at the 0.05 level.

3.1.4 Analysis indicates that rubber type and temperature influence the shear susceptibility constant in the F-tube. Average results at 77F are 0.42 for TPO44 rubber and 0.51 for GT274, at 39.2F are 0.79 for TPO44 and 1.10 for GT274, and at -20F, 0.24 for TPO44 and 0.28 for GT274. These results indicate that at 39.2F, the asphalt-rubber mixtures tested are close to being Newtonian, while at 77 and -20F, materials tested are pseudo-plastic.

### 3.2 Schweyer Rheometer Apparent Viscosity ($\eta_{0.05}$) F-tube

3.2.1 Measured apparent viscosity data using the F-tube are tabulated in Appendix B in Table B-1 and plotted in Figures B1 and B2.

3.2.2 In order to satisfy variance homogeneity requirements, logarithmic transformations of the data were required prior to analysis. Log transformed data are tabulated in Appendix B in Table B-2.

3.2.3 The ANOVA summary for log apparent viscosity, F-tube is tabulated in Table B-3.

3.2.3.1 Rubber concentration is a significant effect at the 0.05 level but not at the 0.01. Temperature and the rubber-temperature interaction are significant at the 0.01 level. All other main effects and interactions are not significant at the 0.05 level.

3.2.4 Analysis indicates that rubber concentration, temperature, and the rubber type-temperature interaction influence apparent viscosity. Average results at 77F are 0.64 x $10^6$ Pa-s for 20 percent rubber and 0.92 x $10^6$ Pa-s for 25 percent, at 39.2F are 83.7 x $10^6$ Pa-s for 20 percent and 400.0 x $10^6$ Pa-s for 25 percent, and at -20F, 99.6 x $10^6$ Pa-s for 20 percent and 97.1 x $10^6$ Pa-s for 25 percent. For 20 percent rubber mixtures, as temperature decreases, apparent viscosity increases as noted in Figure B1. For 25 percent rubber at 39.2F, the average result of 400 x $10^6$ Pa-s may be misleading due to a very high observation (2500 x $10^6$ Pa-s) for TPO44 rubber which may be an outlying value. This value may be the cause of the indicated rubber concentration effect and the rubber type-temperature interaction.

3.3 Force-Ductility Load at Failure

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

3.3.2 Analyzed load at failure data are tabulated in Table C-2 and plotted in Figures C1 and C2. Each entry in Table C-2 is the mean of three measurements from Table C-1.

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

3.3.3.1 Rubber type, temperature, and the rubber-temperature interaction are significant effects at the 0.01 level. All other main effects and interactions are not significant at the 0.05 level.

3.3.4 Analysis indicates that rubber type, temperature, and the rubber-temperature interaction influence load at failure. Average results at 77F are .67 pounds for TPO44 rubber and .55 pounds for GT274, at 39.2F, 17.9 pounds for TPO44 and 15.5 pounds for GT274, and at -20F, 45.8 pounds for TPO44 and 71.6 pounds for GT274. The effect of temperature is that as temperature decreases, load at failure increases. Loads at failure at either 77 or 39.2F are approximately the same for TPO44 and GT274 rubber, but at -20F, average load at failure for GT274 is higher than for TPO44 (71.6 pounds for GT274 compared to 45.8 pounds for TPO44). These trends can be seen in Figures C-1 and C-2. This tends to indicate that mixtures containing GT274 rubber get stronger at low temperatures than mixtures containing TPO44 rubber.

3.4 Force-Ductility Elongation at Failure

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

3.4.2 Reduced elongation at failure data are tabulated in Table D2 and plotted in Figures D1 and D2. Each entry in Table D-2 is the mean of three values from Table D-1.

3.4.3 In order to satisfy variance homogeneity requirements, square root $\sqrt{}$ log transformations of the data were required. Analyzed data are tabulated in Table D-3.

3.4.4 The ANOVA summary for elongation at failure is tabulated in Table D-4.

3.4.4.1 Rubber type, rubber concentration, temperature, the rubber type-temperature interaction, and the concentration-rubber type-temperature interaction, and the four-way interaction are significant effects at the 0.01 level. The concentration-temperature interaction is significant at the 0.05 level but not at the 0.01. Asphalt and other interactions are not significant at the 0.05 level.

3.4.5 Analysis indicates that rubber type, rubber concentration, temperature, and several interactions influence elongation at failure results. Lowest elongation at failure results were at -20F (overall average of 16.3 mm). For TPO44 mixtures, elongations at failure at 39.2F were greater than at 77F, which is contrary to the manner in which asphalt cement would behave. For TPO44 rubber, average result was 108 mm at 77F compared to 206 mm at 39.2F. These reduced elongations at 77F may be due to quick specimen necking into a thin thread which was noted during testing at 77F which did not occur to as great an extent at 39.2F.

For GT274 mixtures with 20 percent rubber, average elongations at failure were 453 mm at 77F and 416 mm at 39.2F, and for 25 percent rubber 366 mm at 77F and 396 mm at 39.2F. The noted increase in elongations at failure for TPO44 rubber between 77 and 39.2 are not noted with 20 percent GT274 rubber mixtures, but are for the 25 percent GT274 mixtures, however, not to as great an extent. This limited data tends to indicate that larger rubber particles and increasing rubber concentrations will tend to decrease elongations at failure at 77F when compared to results at 39.2F.

3.5 Force-Ductility Engineering Stress at Failure

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

3.5.2 Reduced engineering stress at failure data which were analyzed are tabulated in Table E-2 and plotted in Figures E1 and E2. Each entry in Table E-2 is the mean of three values in Table E-1.

3.5.3 The ANOVA summary for engineering stress at failure is tabulated in Table E-3.

3.5.3.1 Rubber type, temperature, and the rubber type-temperature interaction are significant effects at the 0.01 level. All other main effects and interactions are not significant at the 0.05 level.

3.5.4 Analysis indicates that rubber type, temperature, and the rubber type-temperature interaction and the rubber concentration-temperature influence engineering stress at failure results. Average results at 77F are 4.2 psi for TPO44 rubber and 3.5 psi for GT274, at 39.2F, 112.8 psi for TPO44 and 81.5 psi for GT274, and at -20F, 285.9 psi for TPO44 and 445.7 psi for GT274. The effect of temperature is that as temperature decreases, engineering stress at failure increases. Engineering stress at failure at 77 and 39.2F are approximately the same for TPO44 and GT274 rubber mixtures, however, a large difference exists between results at -20F for TPO44 and GT274 mixtures (285.9 psi for TPO44 compared to 445.7 psi for GT274). These trends can be seen in Figures E1 and E2. These results indicate that mixtures containing GT274 rubber are stronger at low temperatures than mixtures containing TPO44 rubber.

3.6 Force-Ductility Engineering Strain at Failure

3.6.1 Measured engineering strain at failure values are tabulated in Appendix F in Table F-1. Three determinations were obtained for each matrix cell replication.

3.6.2 Reduced engineering strain at failure data are tabulated in Table F-2 and are plotted in Figures F1 and F2. Each entry in Table F-2 is the mean of three values from Table F-1.

3.6.3 In order to satisfy variance homogeneity requirements, log transformations of the data were required. Analyzed data are tabulated in Table F-3.

3.6.4 The ANOVA summary for log of engineering strain at failure is tabulated in Table F-4.

3.6.4.1 Rubber type, temperature, and the rubber type-temperature interaction are significant effects at the 0.01 level. Rubber concentration, and the rubber concentration-temperature interaction are significant at the 0.05 level but not at the 0.01 level. Asphalt and other interactions are not significant at the 0.05 level.

3.6.5 Analysis indicates that rubber type, rubber concentration, temperature, and several interactions influence engineering strain at failure results. Lowest engineering strain at failure results were at -20F (overall average of 0.33 mm/mm). Lower engineering strain at failure at 77F when compared to results at 39.2F were noted for TPO44 mixtures while comparable results were noted for GT274 mixtures. The effect is similar to that with elongation at failure as discussed in Section 3.4.5 of this report.

3.7 Force-Ductility True Stress at Failure

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

3.7.2 Reduced true stress at failure data are tabulated in Appendix G in Table G-2 and plotted in Figures G1 and G2. Each entry in Table G-2 is the mean of three values from Table G-1.

3.7.3 In order to satisfy variance homogeneity requirements, log transformations of the data were required. Analyzed data are tabulated in Table G-3.

3.7.4 The ANOVA summary for log of true stress at failure data is tabulated in Table G-4.

3.7.4.1 Rubber type, temperature, and the rubber type-temperature interaction are significant effects at the 0.01 level. Asphalt, the concentration-rubber interaction, and the asphalt-temperature interaction are significant at the 0.05 level but not at the 0.01. Rubber concentration and other interactions are not significant at the 0.05 level.

3.7.5 Analysis indicates that rubber type, asphalt, temperature and several interactions influence true stress at failure results. Lowest true stress at failure results are at 77F (overall average of 21.7 psi) and highest results are at 39.2F (697 psi overall average). Results at -20F are lower than at 39.2F which is contrary to engineering stress at failure results. These trends can be seen in Figures G1 and G2. The reason for higher results at 39.2F is due to the specimen cross sectional area used in calculations. At 39.2F, very small cross sectional areas are used (when compared to the cross section at failure at -20F) as cross sectional areas are calculated based on specimen initial gage length and elongation at failure assuming constant specimen volume between gage points as discussed in Section 6.3.3.5 of the project Summary Report (1).

3.8 Force-Ductility True Strain at Failure

3.8.1 Measured true strain at failure data are tabulated in Appendix H in Table H-1. Three determinations were obtained for each matrix cell replication.

3.8.2 Reduced true strain at failure data are tabulated in Appendix H in Table H-2 and plotted in Figures H1 and H2. Each entry in Table H-2 is the mean of three values from Table H-1.

3.8.3 In order to satisfy variance homogeneity requirements, log transformations of the data were required. Analyzed data are tabulated in Table H-3.

3.8.4 The ANOVA summary for log of true strain at failure is tabulated in Table H-4.

3.8.4.1 Rubber type, temperature, the rubber type-temperature interaction, and the concentration-rubber-temperature interaction are significant effects at the 0.01 level. Rubber concentration and asphalt are significant effects at the 0.05 level but not at the 0.01. Other interactions are not significant at the 0.05 level.

3.8.5 Analysis indicates that rubber type, asphalt, rubber concentration, temperature, and several interactions influence true strain at failure results. Lowest true strain at failure results are at -20F (0.28 mm/mm overall average). Lower true strain at failure at 77F when compared to results at 39.2F were noted for TPO44 mixtures, while comparable results were noted for GT274 mixtures. These trends are noted in Figures H1 and H2. The effect is similar to that with elongation at failure as discussed in Section 3.4.5 of this report.

3.9 Force-Ductility Engineering Creep Compliance at Failure

3.9.1 Calculated engineering creep compliance data are tabulated in Appendix I in Table I-1. Three determinations were made for each matrix cell replication.

3.9.2 Reduced engineering creep compliance at failure data which were analyzed are tabulated in Table I-2 and plotted in Figures I1 and I2. Each entry in Table I-2 is the mean of three values from Table I-1.

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

3.9.3.1 Rubber type, asphalt, temperature, the rubber type-temperature interaction, the concentration-temperature interaction, and the asphalt-temperature interaction are significant effects at the 0.01 level. Concentration, the asphalt-rubber type interaction, and the asphalt-rubber type-temperature interaction are significant at the 0.05 level but not at the 0.01. Other interactions are not significant at the 0.05 level.

3.9.4 Analysis indicates that all main effects and several interactions influence engineering creep compliance at failure results. Average results at 77F are .57 $psi^{-1}$ for TPO44 rubber and 2.44 $psi^{-1}$ for GT274, at 39.2F, 0.04 $psi^{-1}$ for TPO44 and .09 $psi^{-1}$ for GT274, and at -20F, .0012 $psi^{-1}$ for TPO44 and .0009 $psi^{-1}$ for GT274. The effect of temperature is that as temperature decreases, engineering creep compliance at failure decreases. At 77 and 39.2F, mixtures containing GT274 rubber have higher average engineering creep compliance at failure results than TPO44 mixtures, while at -20F, GT274 mixtures have slightly lower average results. This indicates that asphalt rubber mixtures which contain GT274 rubber have a higher degree of temperature susceptibility than mixtures containing TPO44 rubber as indicated by engineering creep compliance at failure. These trends are noted in Figures I1 and I2.

## 3.10 Force-Ductility True Creep Compliance at Failure

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

3.10.2 Reduced true creep compliance data are tabulated in Table J-2 and plotted in Figures J1 and J2.

3.10.3 In order to satisfy variance homogeneity requirements, log transformations of the data were required. For ease of calculation, the negative log of the data were analyzed. Analyzed data are tabulated in Table J-3.

3.10.4 The ANOVA summary for log of true creep compliance at failure is tabulated in Table J-4.

3.10.4.1 Rubber type, asphalt and temperature, are significant effects at the 0.01 level. Rubber concentration, the rubber-temperature interaction, and the asphalt-temperature interaction are significant at the 0.05 level but not at the 0.01 level. Other interactions are not significant at the 0.05 level.

3.10.5 Analysis indicates that all main effects and two interactions influence true creep compliance at failure. Average results at 77F are .0901 $psi^{-1}$ for TPO44 rubber and .0751 $psi^{-1}$ for GT274, at 39.2F, .0031 $psi^{-1}$ for TPO44 and .0027 $psi^{-1}$ for GT274, and at -20F, 0.0008 $psi^{1}$ for TPO44 and .0004 $psi^{1}$ for GT274. The effect of temperature is that as temperature decreases true creep compliance at failure decreases. At 77 and 39.2F, average results for TPO44 and GT274 rubbers are approximately the same, while, at -20F, TPO44 mixtures have higher average results (.0008 $psi^{-1}$ average) than GT274 mixtures (.0004 $psi^{-1}$ average). These results indicate differences in temperature susceptibilities of mixtures containing TPO44 and GT274 rubber as measured by true creep compliance at failure. These trends are noted in Figures J1 and J2.

3.11 Force-Ductility Maximum True Creep Compliance

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

3.11.2 Reduced maximum true creep compliance data are tabulated in Appendix K in Table K-2 and plotted in Figures K1 and K2. Each entry in Table K-2 is the mean of three values in Table K-1.

3.11.3 In order to satisfy variance homogeneity requirements, log transformations of the data were required. For ease of calculation, negative logs of the data were analyzed. Analyzed data are tabulated in Table K-3.

3.11.4 The ANOVA summary for log of maximum true creep compliance data are tabulated in Table K-4.

3.11.4.1 Asphalt, temperature, the rubber-temperature interaction, the concentration-temperature interaction, and the asphalt-temperature interaction are significant at the 0.01 level. Rubber type and the concentration-rubber interaction are significant at the 0.05 level but not at the 0.01. Rubber concentration and other interactions are not significant at the 0.05 level.

3.11.5 Analysis indicates that rubber type, asphalt, temperature, and several interactions influence maximum true creep compliance. Average results at 77F are .0917 $psi^{-1}$ for TPO44 rubber and .1120 $psi^{-1}$ for GT274, at 39.2F, .00481 $psi^{-1}$ for TPO44 and .00756 $psi^{-1}$ for GT274, and at -20F, .00079 $psi^{-1}$ for TPO44 and .00056 $psi^{-1}$ for GT274. These results indicate that the effect of temperature is that as temperature decreases maximum true creep compliance decreases. These trends are noted in Figures J1 and J2.

3.12 Force-Ductility Time to Maximum True Creep Compliance

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

3.12.2 Reduced time to maximum true creep compliance data are tabulated in Appendix L in Table L-2 and plotted in Figures L1 and L2. Each entry in Table L-2 is the mean of three values in Table L-1.

3.12.3 Numerous attempts were made to transform data to satisfy variance homogeneity requirements, but all were unsuccessful. Therefore, ANOVA was not performed on time to maximum true creep compliance data.

3.12.4 Average result at 77F is 12.1 minutes, at 39.2F, 10.2 minutes, and at -20F, 1 minute. Results indicate that as temperature decreases time to maximum true creep compliance decreases. This trend can be seen in Figures L1 and L2.

## 4.0 CONCLUSIONS

4.1 A summary of four-way ANOVA results is tabulated in Table 1. This table indicates independent variables and interactions which were found to significantly affect test parameters studied. From Table 1, it is noted that temperature influences all parameters studied and that rubber type and concentration influence nearly all parameters studied (as noted and discussed in Volume I of this investigation). Additionally, several interactions exist including a rubber type-temperature interaction and an asphalt-temperature interaction.

4.2 The effect of temperature is to stiffen and strengthen mixtures as temperature is lowered as evidenced by increased loads and stresses at failure, increased viscosity, and decreased elongation, strains, and compliances at failure.

4.3 The existance of the rubber-temperature and asphalt-temperature interactions for several parameters indicate that asphalt-rubber mixtures containing the different rubber and asphalt types studied react differently at different temperatures, or, more simply stated, have differing temperature susceptibilities.

Table 1 Summary of Four-Way ANOVA Results at the 0.05 Level of Significance

| | R | Q | A | T | RQ | RA | RT | QA | QT | AT | RQA | RAT | QAT | RQT | RQAT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Schweyer Rheometer | | | | | | | | | | | | | | | |
| Constant (C), F-tube | Y | - | - | Y | - | - | - | - | - | - | - | - | - | - | - |
| App.Viscosity, F-tube | - | Y | - | Y | - | - | Y | - | - | - | - | - | - | - | - |
| Force-Ductility | | | | | | | | | | | | | | | |
| Load at Failure | Y | - | - | Y | - | - | Y | - | - | - | - | - | - | - | - |
| Elongation at Failure | Y | Y | - | Y | | - | Y | - | Y | | - | | | Y | |
| Eng. Stress at Failure | Y | - | - | Y | - | - | Y | - | - | - | - | - | - | - | - |
| Eng. Strain at Failure | Y | Y | - | Y | - | - | Y | - | - | - | - | - | - | Y | - |
| True Stress at Failure | Y | - | Y | Y | Y | - | Y | - | - | Y | - | - | - | - | - |
| True Strain at Failure | Y | Y | Y | Y | - | - | Y | - | - | - | - | - | - | Y | - |
| Eng. Creep Compliance | Y | Y | Y | Y | - | Y | Y | - | Y | Y | - | Y | - | - | - |
| True Creep Compliance | Y | Y | Y | Y | - | - | Y | - | - | Y | - | - | - | - | - |
| Max.True Creep Compliance | Y | - | Y | Y | Y | - | 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.

# APPENDIX A

## SCHWEYER RHEOMETER CONSTANT

## (C), F-TUBE

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

a. Measured and Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .33 | .71 | .68 | .90 | .15 | .31 |
| | | .42 | .63 | .59 | 1.7 | .29 | .23 |
| | 25% | .55 | .66 | 1.1 | 1.1 | .37 | .22 |
| | | .17 | .59 | .70 | 1.5 | .19 | .25 |
| AR1000 | 20% | .31 | .42 | .13 | 1.1 | .32 | .28 |
| | | .51 | .26 | .98 | .92 | .20 | .32 |
| | 25% | .64 | .44 | 1.1 | .75 | .15 | .26 |
| | | .42 | .37 | .98 | .82 | .20 | .33 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .38 | .67 | .64 | 1.30 | .22 | .27 |
| | | s | .08 | .07 | .08 | .71 | .12 | .07 |
| | | cv | 21.3 | 10.6 | 12.6 | 54.5 | 56.4 | 26.3 |
| | 25% | $\bar{x}$ | .36 | .63 | .90 | 1.30 | .28 | .24 |
| | | s | .34 | .06 | .35 | .35 | .16 | .03 |
| | | cv | 93.5 | 9.9 | 39.4 | 27.3 | 57.0 | 11.3 |
| AR1000 | 20% | $\bar{x}$ | .41 | .34 | .56 | 1.01 | .26 | .30 |
| | | s | .18 | .14 | .75 | .16 | .11 | .04 |
| | | cv | 43.2 | 41.7 | 135.7 | 15.8 | 40.9 | 11.8 |
| | 25% | $\bar{x}$ | .53 | .41 | 1.04 | .79 | .18 | .30 |
| | | s | .19 | .06 | .11 | .06 | .04 | .06 |
| | | cv | 36.8 | 15.3 | 10.2 | 7.9 | 25.3 | 21.0 |

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

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 0.2685 | 0.2685 | 6.11 | 4.26 | 7.82 |
| Q | 1 | 0.0285 | 0.0285 | 0.65 | 4.26 | 7.82 |
| A | 1 | 0.0945 | 0.0945 | 2.15 | 4.26 | 7.82 |
| T | 2 | 3.9565 | 1.9782 | 45.05 | 3.40 | 5.61 |
| RQ | 1 | 0.0963 | 0.0963 | 2.19 | 4.26 | 7.82 |
| RA | 1 | 0.1788 | 0.1788 | 4.07 | 4.26 | 7.82 |
| RT | 2 | 0.1716 | 0.0858 | 1.95 | 3.40 | 5.61 |
| QA | 1 | 0.0013 | 0.0013 | 0.03 | 4.26 | 7.82 |
| QT | 2 | 0.0453 | 0.0226 | 0.52 | 3.40 | 5.61 |
| AT | 2 | 0.0741 | 0.0370 | 0.84 | 3.40 | 5.61 |
| RQA | 1 | 0.0072 | 0.0072 | 0.17 | 4.26 | 7.82 |
| RAT | 2 | 0.1567 | 0.0783 | 1.78 | 3.40 | 5.61 |
| QAT | 2 | 0.0170 | 0.0085 | 0.19 | 3.40 | 5.61 |
| RQT | 2 | 0.1432 | 0.0716 | 1.63 | 3.40 | 5.61 |
| RQAT | 2 | 0.0500 | 0.0250 | 0.57 | 3.40 | 5.61 |
| Error | 24 | 1.0538 | 0.0439 | | | |
| TOTAL | 47 | 6.3438 | | | | |

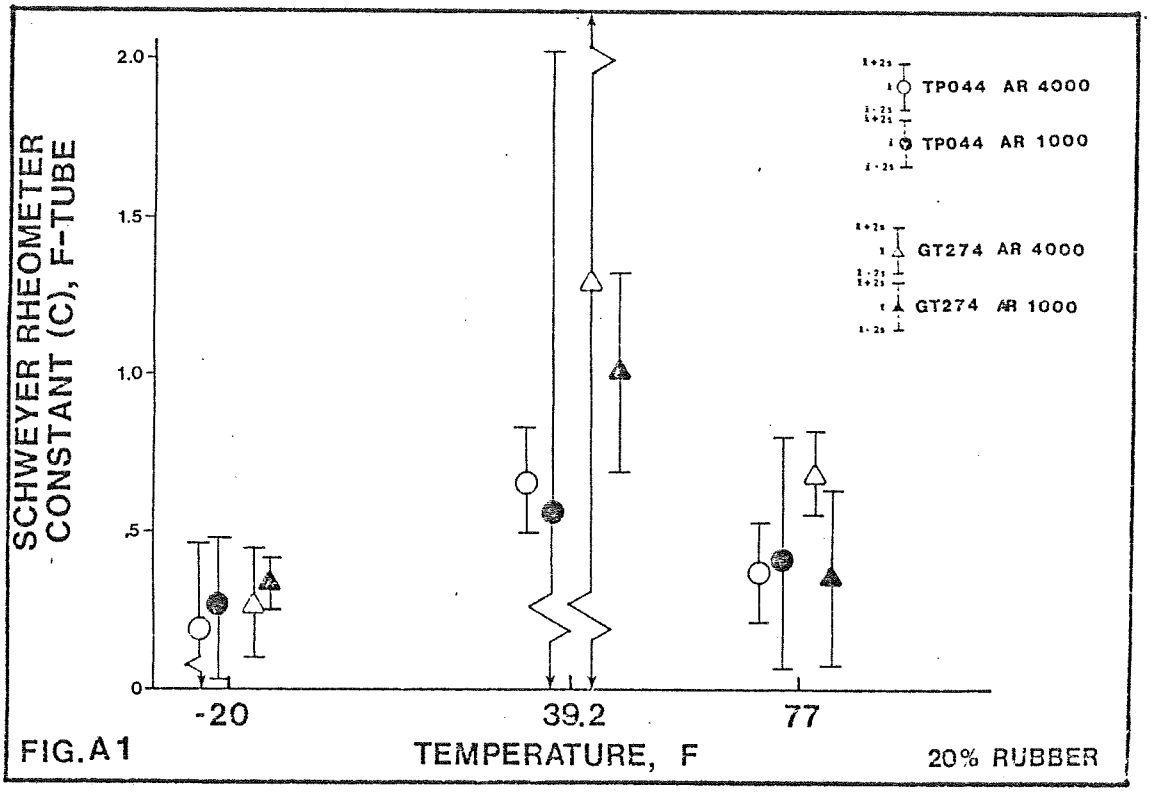
SCHWEYER RHEOMETER
CONSTANT (C), F-TUBE
2.0
1.5
1.0
.5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. A1

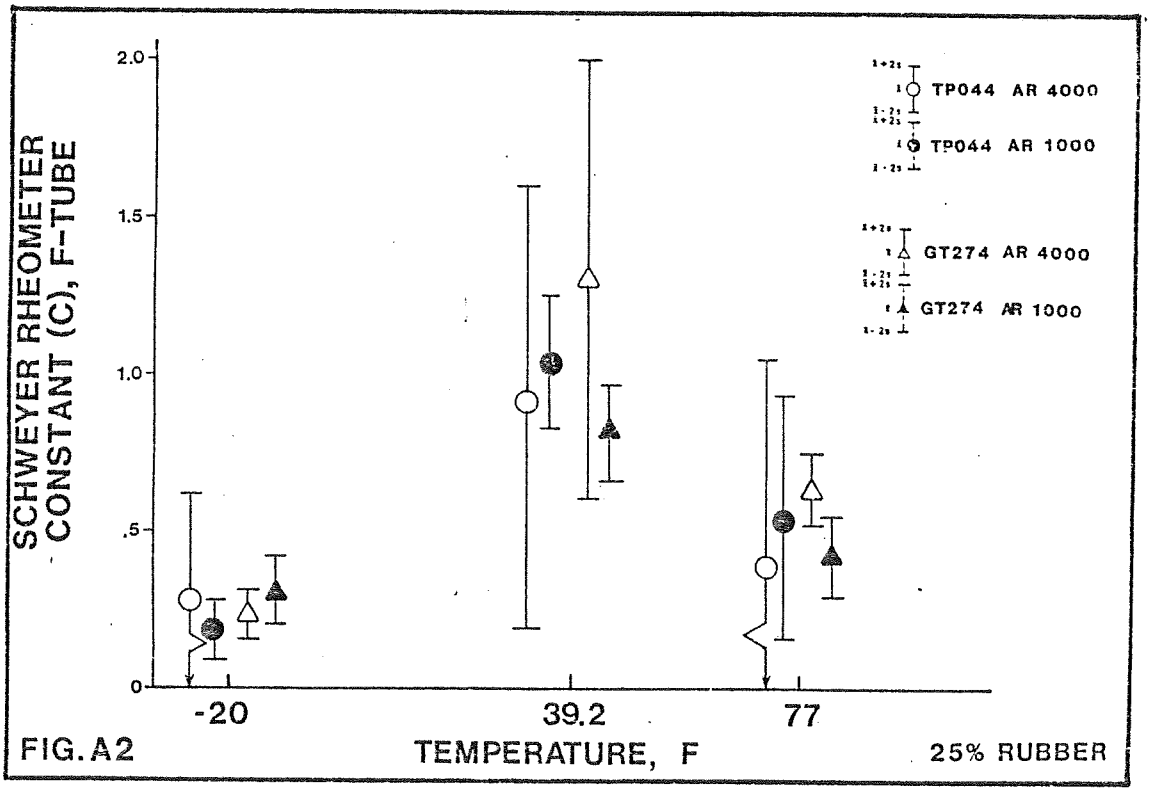
SCHWEYER RHEOMETER
CONSTANT (C), F-TUBE
2.0
1.5
1.0
.5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. A2

# APPENDIX B

## VISCOSITY ($\eta_{0.05}$) BY SCHWEYER RHEOMETER

F-TUBE

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

a. Measured Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .47 | 1.2 | 24 | 34 | 64 | 110 |
| | | .65 | 1.1 | 410 | 21 | 110 | 79 |
| | 25% | .71 | 2.0 | 130 | 34 | 210 | 76 |
| | | .39 | 1.3 | 150 | 49 | 69 | 98 |
| AR1000 | 20% | .43 | .42 | 95 | 35 | 130 | 100 |
| | | .40 | .40 | 8.8 | 42 | 84 | 120 |
| | 25% | .93 | .78 | 2500 | 16 | 60 | 89 |
| | | .74 | .50 | 230 | 91 | 75 | 100 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .56 | 1.15 | 217 | 27.5 | 87 | 94.5 |
| | | s | .1595 | .0886 | 34.9 | 11.52 | 40.76 | 27.47 |
| | | cv | 28.5 | 7.7 | 157.6 | 41.9 | 46.9 | 20.1 |
| | 25% | $\bar{x}$ | .55 | 1.65 | 140 | 41.5 | 139.5 | 87 |
| | | s | .2835 | .6202 | 17.72 | 13.29 | 124.93 | 19.49 |
| | | cv | 51.6 | 37.6 | 16.7 | 32.0 | 89.6 | 22.4 |
| AR1000 | 20% | $\bar{x}$ | .42 | .41 | 51.9 | 38.5 | 107 | 110 |
| | | s | .0266 | .0177 | 76.37 | 6.20 | 40.76 | 17.72 |
| | | cv | 6.4 | 4.3 | 147.2 | 16.1 | 38.1 | 16.1 |
| | 25% | $\bar{x}$ | .84 | .64 | 1365 | 53.5 | 67.5 | 94.5 |
| | | s | .1683 | .2481 | 2011.22 | 66.45 | 13.29 | 9.75 |
| | | cv | 20.2 | 38.8 | 147.3 | 124.2 | 19.7 | 10.3 |

Table B-2 Log Schweyer Rheometer $\eta_{0.05}$, $10^6$ Pa-s, F-tube

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | -.3279 | .0792 | 1.3802 | 1.5315 | 1.8062 | 2.0414 |
| | | -.1871 | .0414 | 2.6128 | 1.3222 | 2.0414 | 1.8976 |
| | 25% | -.1487 | .3010 | 2.1138 | 1.5315 | 2.3222 | 1.8808 |
| | | -.4089 | .1139 | 2.1761 | 1.6902 | 1.8388 | 1.9912 |
| AR1000 | 20% | -.3665 | -.3768 | 1.9777 | 1.5441 | 2.1139 | 2.0000 |
| | | -.3979 | -.3979 | .9445 | 1.6232 | 1.9243 | 2.0792 |
| | 25% | -.0315 | -.1079 | 3.3979 | 1.2041 | 1.7782 | 1.9494 |
| | | -.1308 | -.3010 | 2.3617 | 1.9590 | 1.8751 | 2.0000 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | -.2575 | .0603 | 1.9965 | 1.4269 | 1.9238 | 1.9695 |
| | | s | .1247 | .0335 | 1.0921 | .1854 | .2084 | .1274 |
| | | cv | 48.4 | 55.5 | 54.7 | 13.0 | 10.8 | 6.5 |
| | 25% | $\bar{x}$ | -.2788 | .2075 | 2.1450 | 1.6109 | 2.0805 | 1.9360 |
| | | s | .2305 | .1658 | .0552 | .1406 | .4283 | .0978 |
| | | cv | -82.7 | 80.0 | 2.6 | 8.7 | 20.6 | 5.1 |
| AR1000 | 20% | $\bar{x}$ | -.3822 | -.3874 | 1.4611 | 1.5837 | 2.0191 | 2.0396 |
| | | s | .0278 | .0187 | .9154 | .0701 | .1630 | .0702 |
| | | cv | 7.3 | 4.8 | 62.7 | 4.4 | 8.3 | 3.4 |
| | 25% | $\bar{x}$ | -0.0812 | -.2045 | 2.8798 | 1.5816 | 1.8267 | 1.9747 |
| | | s | .0880 | .1711 | .9181 | .6688 | .0859 | .0448 |
| | | cv | 108.4 | -83.7 | 31.9 | 42.3 | 4.7 | 2.3 |

Table B-3 ANOVA Summary, Schweyer Rheometer, Log Apparent Viscosity, F-tube

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 0.2281 | 0.2281 | 2.25 | 4.26 | 7.82 |
| Q | 1 | 0.4583 | 0.4583 | 4.53 | 4.26 | 7.82 |
| A | 1 | 0.0125 | 0.0125 | 0.12 | 4.26 | 7.82 |
| T | 2 | 46.4721 | 23.2360 | 229.58 | 3.40 | 5.61 |
| RQ | 1 | 0.1358 | 0.1358 | 1.34 | 4.26 | 7.82 |
| RA | 1 | 0.0316 | 0.0316 | 0.31 | 4.26 | 7.82 |
| RT | 2 | 1.1490 | 0.5745 | 5.68 | 3.40 | 5.61 |
| QA | 1 | 0.0738 | 0.0738 | 0.73 | 4.26 | 7.82 |
| QT | 2 | 0.4442 | 0.2220 | 2.19 | 3.40 | 5.61 |
| AT | 2 | 0.1256 | 0.0620 | 0.62 | 3.40 | 5.61 |
| RQA | 1 | 0.1991 | 0.1991 | 1.97 | 4.26 | 7.82 |
| RAT | 2 | 0.1522 | 0.0760 | 0.75 | 3.40 | 5.61 |
| QAT | 2 | 0.2703 | 0.1350 | 1.34 | 3.40 | 5.61 |
| RQT | 2 | 0.3521 | 0.1760 | 1.74 | 3.40 | 5.61 |
| RQAT | 2 | 0.3978 | 0.1990 | 1.97 | 3.40 | 5.61 |
| Error | 24 | 1.4290 | 0.1012 | | | |
| TOTAL | 47 | 52.9323 | | | | |

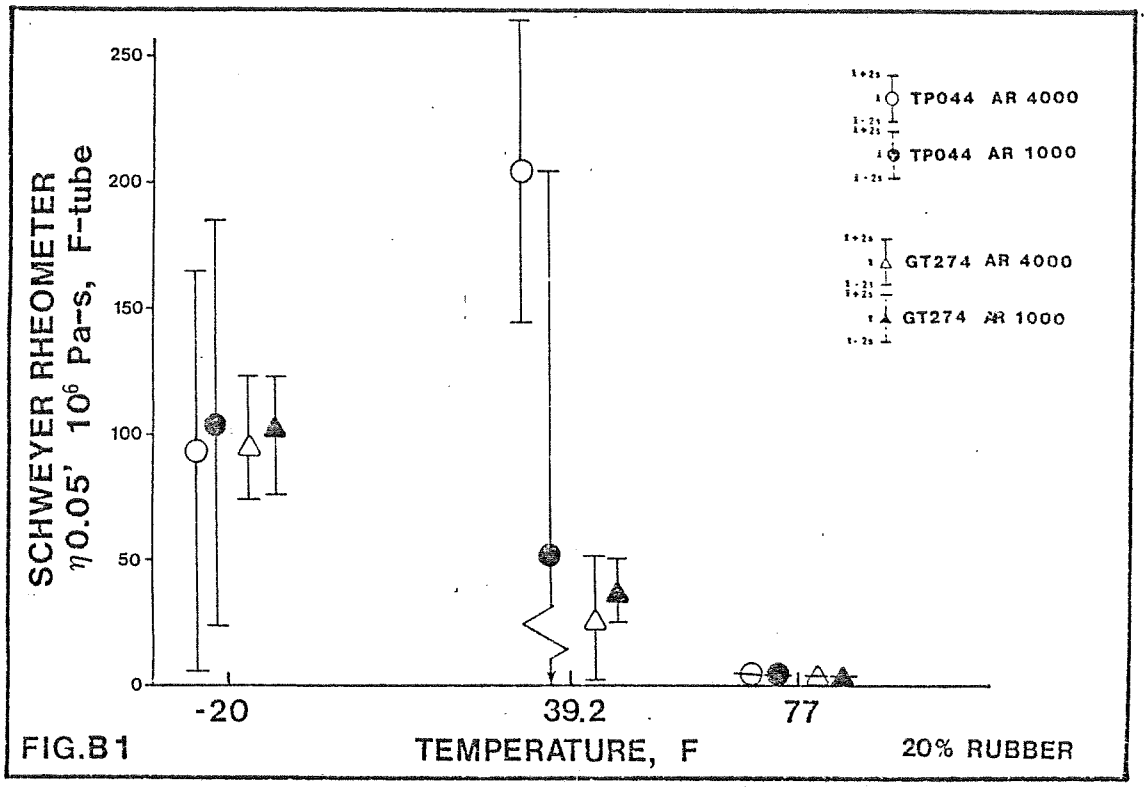
SCHWEYER RHEOMETER
η0.05' 10⁶ Pa-s, F-tube
250
200
150
100
50
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG.B1

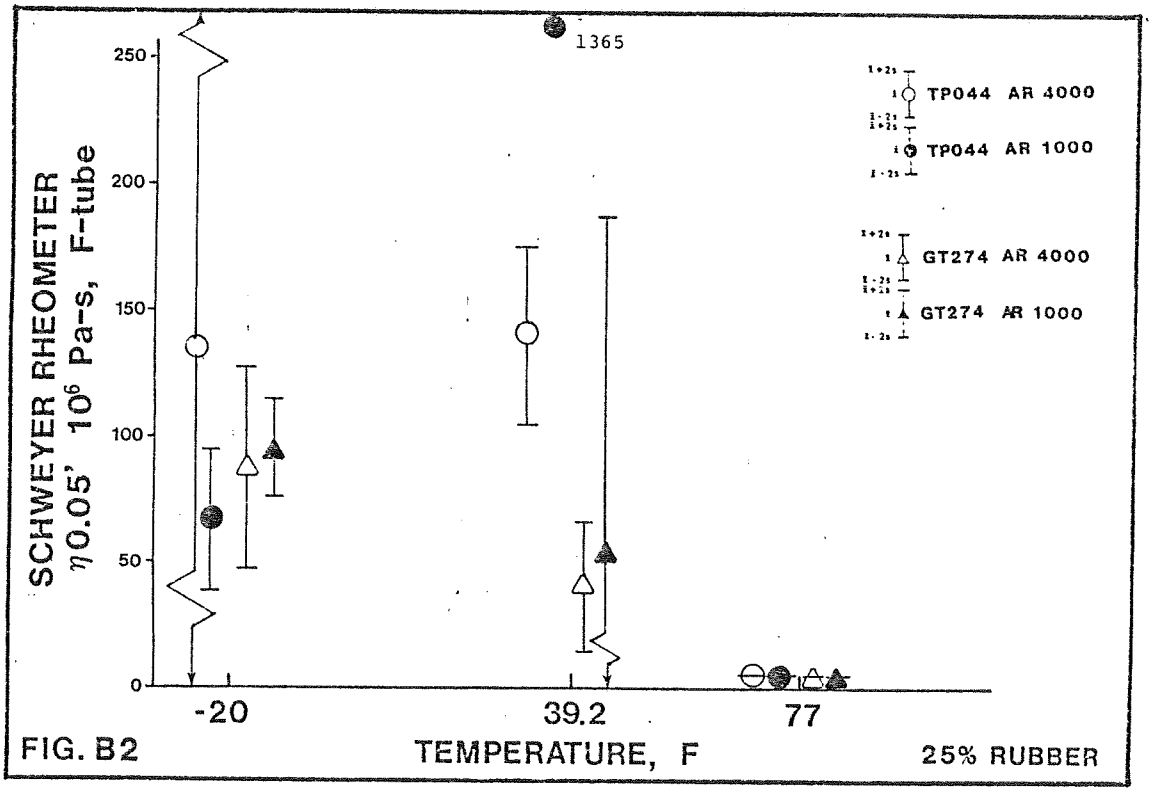
SCHWEYER RHEOMETER
η0.05' 10⁶ Pa-s, F-tube
1365
250
200
150
100
50
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. B2

# APPENDIX C

## FORCE-DUCTILITY LOAD AT FAILURE

Table C-1 Load at Failure, pounds

a. Measured Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .6124<br>.7199<br>.6124 | .4241<br>.5048<br>.4510 | 23.04<br>21.62<br>18.79 | 18.10<br>18.98<br>19.00 | 41.327<br>48.319<br>24.116 | 82.472<br>84.623<br>77.093 |
| | | .6392<br>.6392<br>.6661 | .6661<br>.6392<br>.58546 | 21.64<br>20.89<br>19.89 | 19.95<br>19.41<br>18.25 | 49.932<br>46.167<br>48.857 | 58.538<br>66.068<br>78.824 |
| | 25% | .8813<br>.7737<br>.9082 | .6661<br>.4779<br>.7468 | 23.71<br>23.47<br>21.29 | 18.17<br>18.93<br>19.22 | 39.176<br>44.016<br>41.865 | 57.731<br>83.816 |
| | | .3006<br>.7737<br>.8813 | .6661<br>.6392<br>.6661 | 23.20<br>22.13<br>18.87 | 19.30<br>19.41<br>18.98 | 47.781<br>43.478<br>55.311 | 80.051<br>62.203<br>75.749 |
| AR1000 | 20% | .4510<br>.4510<br>.4510 | .4779<br>.3434<br>.4510 | 9.27<br>13.28<br>10.12 | 11.10<br>10.60<br>10.80 | 46.167<br>23.578<br>36.486 | 86.505<br>86.505<br>94.573 |
| | | .4510<br>.4779<br>.4779 | .7468<br>.5048<br>.4510 | 13.79<br>12.74<br>12.10 | 10.00<br>10.27<br>10.94 | 42.403<br>44.554<br>55.311 | 55.741<br>77.228<br>73.060 |
| | 25% | .77370<br>.69303<br>.8813 | .6392<br>.5048<br>.4510 | 17.18<br>18.68<br>20.24 | 12.88<br>12.58<br>13.90 | 57.462<br>54.235<br>55.849 | 46.167<br>*<br>* |
| | | .7200<br>.7200<br>.6661 | .5048<br>.5048<br>.4510 | 16.21<br>16.37<br>14.19 | 13.70<br>14.00<br>12.70 | 61.227<br>32.184<br>58.000 | 75.458<br>*<br>* |

*Note: Specimens fractured before readings could be taken.

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .6482 | .5451 | 20.98 | 18.95 | 43.120 | 74.603 |
| | | s | .0405 | .1002 | 1.489 | .697 | 9.798 | 10.171 |
| | | cv | 6.24 | 18.39 | 7.10 | 3.68 | 22.72 | 13.63 |
| | 25% | $\bar{x}$ | .8365 | .6437 | 22.11 | 19.00 | 45.271 | 71.910 |
| | | s | .0606 | .0891 | 1.831 | .447 | 5.668 | 11.380 |
| | | cv | 7.24 | 13.83 | 8.28 | 2.35 | 12.52 | 15.83 |
| AR1000 | 20% | $\bar{x}$ | .4600 | .4958 | 11.88 | 10.62 | 41.417 | 78.935 |
| | | s | .0139 | .1356 | 1.806 | .418 | 10.667 | 13.671 |
| | | cv | 3.02 | 27.16 | 15.20 | 3.93 | 25.76 | 17.32 |
| | 25% | $\bar{x}$ | .7424 | .5093 | 17.15 | 13.26 | 53.160 | 60.313 |
| | | s | .0769 | .0689 | 2.104 | .676 | 10.539 | 25.07 |
| | | cv | 10.35 | 13.53 | 12.27 | 5.10 | 19.83 | 41.57 |

Table C-2 Load at Failure, pounds

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .648 | .460 | 21.1 | 18.7 | 37.9 | 81.4 |
| | | .648 | .630 | 20.8 | 19.2 | 48.3 | 67.8 |
| | 25% | .854 | .630 | 22.8 | 18.8 | 41.7 | 70.8 |
| | | .819 | .657 | 21.4 | 19.2 | 48.9 | 72.7 |
| AR1000 | 20% | .451 | .424 | 10.9 | 10.8 | 35.4 | 89.2 |
| | | .469 | .568 | 12.9 | 10.4 | 47.4 | 68.7 |
| | 25% | .783 | .532 | 18.7 | 13.1 | 55.8 | 46.2 |
| | | .700 | .487 | 14.6 | 13.5 | 50.5 | 75.5 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .648 | .549 | 21.0 | 19.0 | 43.1 | 74.6 |
| | | s | 0 | .144 | .22 | .44 | 9.2 | 12.1 |
| | | cv | 0 | 26.1 | 1.2 | 2.3 | 21.4 | 16.2 |
| | 25% | $\bar{x}$ | .837 | .644 | 22.1 | 19.0 | 45.3 | 71.8 |
| | | s | .03 | .02 | 1.24 | .35 | 6.38 | 1.68 |
| | | cv | 3.7 | 3.7 | 5.6 | 1.9 | 14.1 | 2.3 |
| AR1000 | 20% | $\bar{x}$ | .460 | .496 | 11.9 | 10.6 | 41.4 | 79.0 |
| | | s | .016 | .128 | 1.77 | .35 | 10.6 | 18.2 |
| | | cv | 3.5 | 25.7 | 14.9 | 3.3 | 25.7 | 23.0 |
| | 25% | $\bar{x}$ | .742 | .510 | 16.7 | 13.3 | 53.2 | 60.9 |
| | | s | .074 | .040 | 3.6 | .35 | 4.70 | 26.0 |
| | | cv | 9.9 | 7.8 | 21.8 | 2.7 | 8.8 | 42.7 |

Table C-3 ANOVA Summary, Load at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 720.09 | 720.09 | 18.96 | 4.26 | 7.82 |
| Q | 1 | 0.41 | 0.41 | 0.01 | 4.26 | 7.82 |
| A | 1 | 72.10 | 72.10 | 1.90 | 4.26 | 7.82 |
| T | 2 | 28724.28 | 14362.14 | 378.15 | 3.40 | 5.61 |
| RQ | 1 | 122.93 | 122.93 | 3.24 | 4.26 | 7.82 |
| RA | 1 | 12.30 | 12.30 | 0.32 | 4.26 | 7.82 |
| RT | 2 | 1966.28 | 983.14 | 25.89 | 3.40 | 5.61 |
| QA | 1 | 0.02 | 0.02 | 0.00 | 4.26 | 7.82 |
| QT | 2 | 30.62 | 15.31 | 0.40 | 3.40 | 5.61 |
| AT | 2 | 131.76 | 65.88 | 1.73 | 3.40 | 5.61 |
| RQA | 1 | 56.02 | 56.02 | 1.48 | 4.26 | 7.82 |
| RAT | 2 | 28.07 | 14.03 | 0.37 | 3.40 | 5.61 |
| QAT | 2 | 17.86 | 8.93 | 0.24 | 3.40 | 5.61 |
| RQT | 2 | 184.08 | 92.04 | 2.42 | 3.40 | 5.61 |
| RQAT | 2 | 97.97 | 48.98 | 1.29 | 3.40 | 5.61 |
| Error | 24 | 911.52 | 37.98 | | | |
| TOTAL | 47 | 33076.37 | | | | |

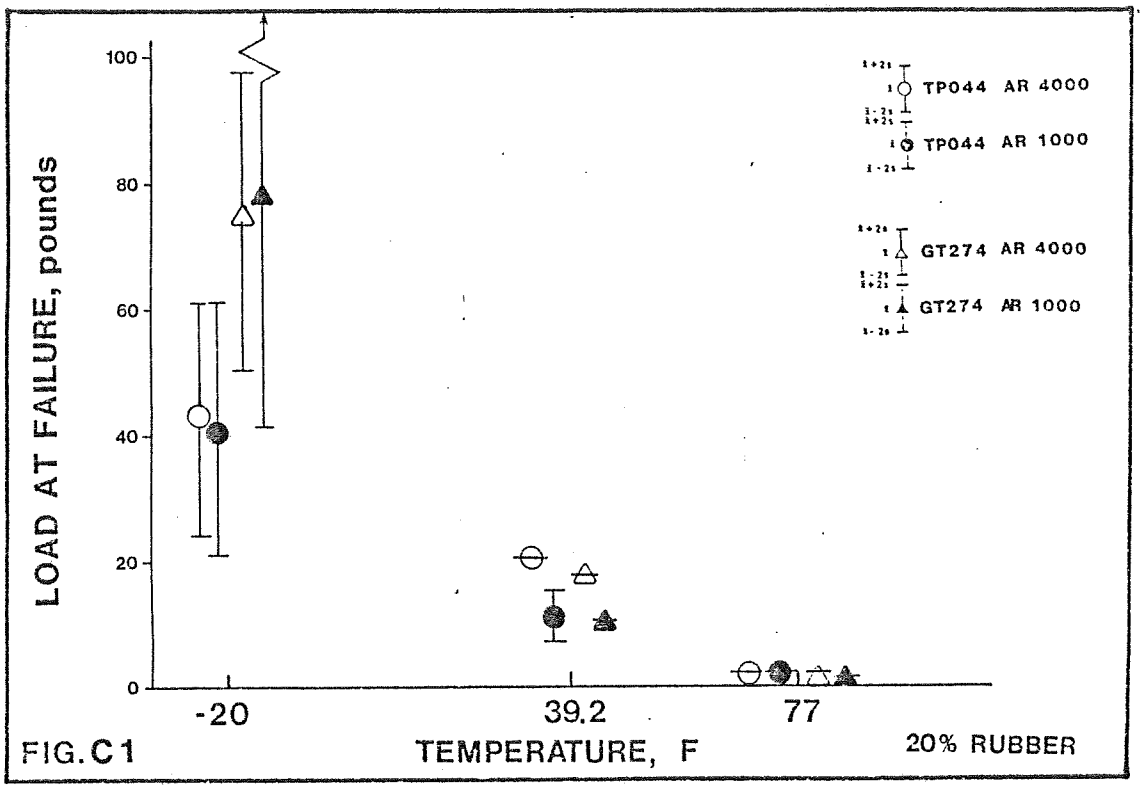
LOAD AT FAILURE, pounds
100
80
60
40
20
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. C1

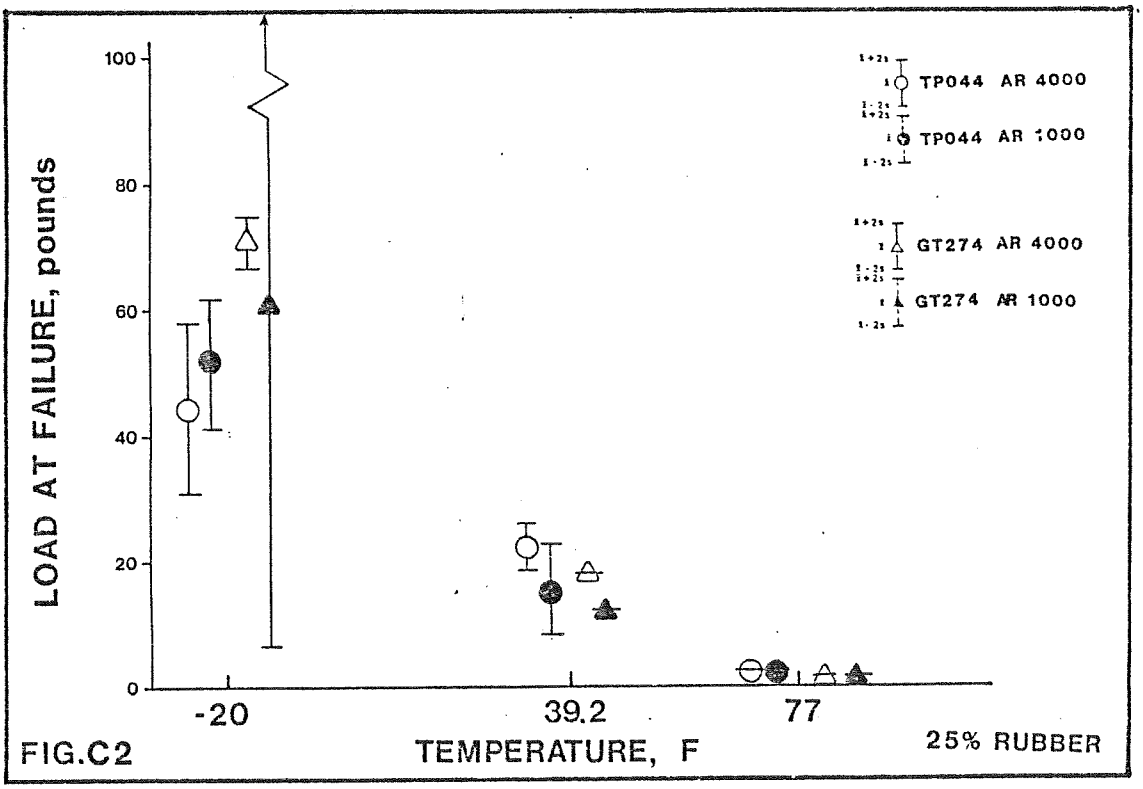
LOAD AT FAILURE, pounds
100
80
60
40
20
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. C2

# APPENDIX D

## FORCE-DUCTILITY ELONGATION AT FAILURE

Table D-1 Elongation at Failure, mm

a. Measured Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 111 | 433 | 201 | 387 | 11 | 13 |
| | | 123 | 377 | 193 | 378 | 16 | 16 |
| | | 107 | 499 | 205 | 388 | 18 | 27 |
| | | 117 | 391 | 202 | 357 | 20 | 20 |
| | | 203 | 298 | 189 | 392 | 17 | 22 |
| | | 184 | 491 | 210 | 412 | 13 | 23 |
| | 25% | 104 | 247 | 178 | 358 | 16 | 16 |
| | | 98 | 72 | 203 | 351 | 20 | 20 |
| | | 55 | 183 | 175 | 376 | 21 | |
| | | 62 | 361 | 174 | 367 | 23 | 21 |
| | | 96 | 380 | 192 | 397 | 18 | 17 |
| | | 68 | 367 | 244 | 346 | 16 | 16 |
| AR1000 | 20% | 113 | 550 | 253 | 499 | 15 | 20 |
| | | 164 | 460 | 235 | 452 | 15 | 20 |
| | | 131 | 498 | 240 | 462 | 13 | 17 |
| | | 100 | 546 | 280 | 409 | 13 | 18 |
| | | 109 | 479 | 209 | 394 | 15 | 20 |
| | | 119 | 412 | 239 | 463 | 20 | 20 |
| | 25% | 122 | 574 | 181 | 451 | 20 | 17 |
| | | 68 | 359 | 183 | 421 | 25 | * |
| | | 108 | 427 | 184 | 445 | 17 | * |
| | | 69 | 520 | 189 | 425 | 20 | 17 |
| | | 73 | 467 | 202 | 406 | 16 | * |
| | | 82 | 442 | 174 | 406 | 20 | * |

*Note: Specimens fractured before readings could be taken.

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 140.83 | 414.83 | 200.00 | 385.67 | 15.83 | 20.17 |
| | | s | 41.59 | 75.98 | 7.75 | 18.01 | 3.31 | 5.04 |
| | | cv | 29.53 | 18.32 | 3.87 | 4.67 | 20.92 | 24.98 |
| | 25% | $\bar{x}$ | 80.50 | 268.33 | 194.33 | 365.83 | 19.00 | 18.00 |
| | | s | 21.20 | 124.16 | 26.84 | 18.71 | 2.83 | 2.35 |
| | | cv | 26.34 | 46.27 | 13.81 | 5.12 | 14.89 | 13.03 |
| AR1000 | 20% | $\bar{x}$ | 122.67 | 490.83 | 242.67 | 446.50 | 15.17 | 19.17 |
| | | s | 22.74 | 52.73 | 23.30 | 38.63 | 2.56 | 1.33 |
| | | cv | 18.54 | 10.74 | 9.60 | 8.65 | 16.90 | 6.93 |
| | 25% | $\bar{x}$ | 87.00 | 464.83 | 185.50 | 425.67 | 19.67 | 17.00 |
| | | s | 22.68 | 74.99 | 9.44 | 19.03 | 3.14 | 0 |
| | | cv | 26.07 | 16.13 | 5.09 | 4.47 | 15.97 | 0 |

Table D-2 Elongation at Failure, mm

a. Reduced Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 114 | 436 | 200 | 384 | 15 | 19 |
| | | 168 | 393 | 200 | 387 | 17 | 22 |
| | 25% | 86 | 167 | 185 | 362 | 19 | 12 |
| | | 75 | 369 | 203 | 370 | 19 | 18 |
| AR1000 | 20% | 136 | 503 | 243 | 471 | 14 | 19 |
| | | 109 | 479 | 243 | 422 | 16 | 19 |
| | 25% | 99 | 453 | 183 | 439 | 21 | 17 |
| | | 75 | 476 | 188 | 412 | 19 | 17 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 141.0 | 414.5 | 200.0 | 385.5 | 16.0 | 20.5 |
| | | s | 47.84 | 38.10 | 0 | 2.66 | 1.77 | 2.66 |
| | | cv | 33.9 | 9.2 | 0 | .7 | 11.1 | 13.0 |
| | 25% | $\bar{x}$ | 80.5 | 268.0 | 194.0 | 366.0 | 19.0 | 15.0 |
| | | s | 9.75 | 178.97 | 15.95 | 7.09 | 0 | 5.32 |
| | | cv | 12.1 | 66.8 | 8.2 | 1.9 | 0 | 35.4 |
| AR1000 | 20% | $\bar{x}$ | 122.5 | 491.0 | 243.0 | 446.5 | 15.0 | 19.0 |
| | | s | 23.92 | 21.26 | 0 | 43.41 | 1.77 | 0 |
| | | cv | 19.5 | 4.3 | 0 | 9.7 | 11.8 | 0 |
| | 25% | $\bar{x}$ | 87.0 | 464.5 | 185.5 | 425.5 | 20.0 | 17.0 |
| | | s | 21.26 | 20.38 | 4.43 | 23.92 | 1.77 | 0 |
| | | cv | 24.4 | 4.4 | 2.4 | 5.6 | 8.9 | 0 |

Table D-3 $\sqrt{\ }$ Log Elongation at Failure

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 1.434 | 1.625 | 1.517 | 1.608 | 1.084 | 1.131 |
| | | 1.492 | 1.611 | 1.517 | 1.609 | 1.109 | 1.159 |
| | 25% | 1.391 | 1.491 | 1.506 | 1.600 | 1.131 | 1.039 |
| | | 1.369 | 1.602 | 1.519 | 1.603 | 1.131 | 1.120 |
| AR1000 | 20% | 1.461 | 1.644 | 1.545 | 1.635 | 1.071 | 1.131 |
| | | 1.427 | 1.637 | 1.545 | 1.620 | 1.097 | 1.131 |
| | 25% | 1.413 | 1.630 | 1.504 | 1.620 | 1.150 | 1.109 |
| | | 1.369 | 1.636 | 1.508 | 1.617 | 1.131 | 1.109 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 1.463 | 1.618 | 1.517 | 1.609 | 1.097 | 1.145 |
| | | s | .061 | .012 | 0 | .001 | .022 | .025 |
| | | cv | 3.5 | .8 | 0 | .1 | 2.0 | 2.2 |
| | 25% | $\bar{x}$ | 1.380 | 1.547 | 1.513 | 1.602 | 1.131 | 1.080 |
| | | s | .019 | .098 | .012 | .003 | 0 | .072 |
| | | cv | 1.4 | 6.4 | .8 | .2 | 0 | 6.6 |
| AR1000 | 20% | $\bar{x}$ | 1.444 | 1.641 | 1.545 | 1.628 | 1.084 | 1.131 |
| | | s | .030 | .000 | 0 | .013 | .023 | 0 |
| | | cv | 2.1 | .4 | 0 | .8 | 2.1 | 0 |
| | 25% | $\bar{x}$ | 1.391 | 1.633 | 1.506 | 1.622 | 1.141 | 1.109 |
| | | s | .039 | .005 | .004 | .008 | .017 | 0 |
| | | cv | 2.8 | .3 | .2 | .5 | 1.5 | 0 |

Table D-4 ANOVA Summary, $\sqrt{\text{Log Elongation}}$ at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | .10983 | .10983 | 181.92 | 4.26 | 7.82 |
| Q | 1 | .00612 | .00612 | 10.14 | 4.26 | 7.82 |
| A | 1 | .00244 | .00244 | 4.04 | 4.26 | 7.82 |
| T | 2 | 1.95984 | .97992 | 1623.16 | 3.40 | 5.61 |
| RQ | 1 | .00074 | .00074 | 1.22 | 4.26 | 7.82 |
| RA | 1 | .00188 | .00188 | 3.11 | 4.26 | 7.82 |
| RT | 2 | .06986 | .03493 | 57.86 | 3.40 | 5.61 |
| QA | 1 | .00126 | .00126 | 2.09 | 4.26 | 7.82 |
| QT | 2 | .00632 | .00316 | 5.24 | 3.40 | 5.61 |
| AT | 2 | .00098 | .00049 | 0.81 | 3.40 | 5.61 |
| RQA | 1 | .00065 | .00065 | 1.07 | 4.26 | 7.82 |
| RAT | 2 | .00169 | .00085 | 1.40 | 3.40 | 5.61 |
| QAT | 2 | .00235 | .00118 | 1.95 | 3.40 | 5.61 |
| RQT | 2 | .00823 | .00412 | 6.82 | 3.40 | 5.61 |
| RQAT | 2 | .00002 | .00001 | 0.02 | 3.40 | 5.61 |
| Error | 24 | .01449 | .00060 | | | |
| TOTAL | 47 | 2.18668 | | | | |

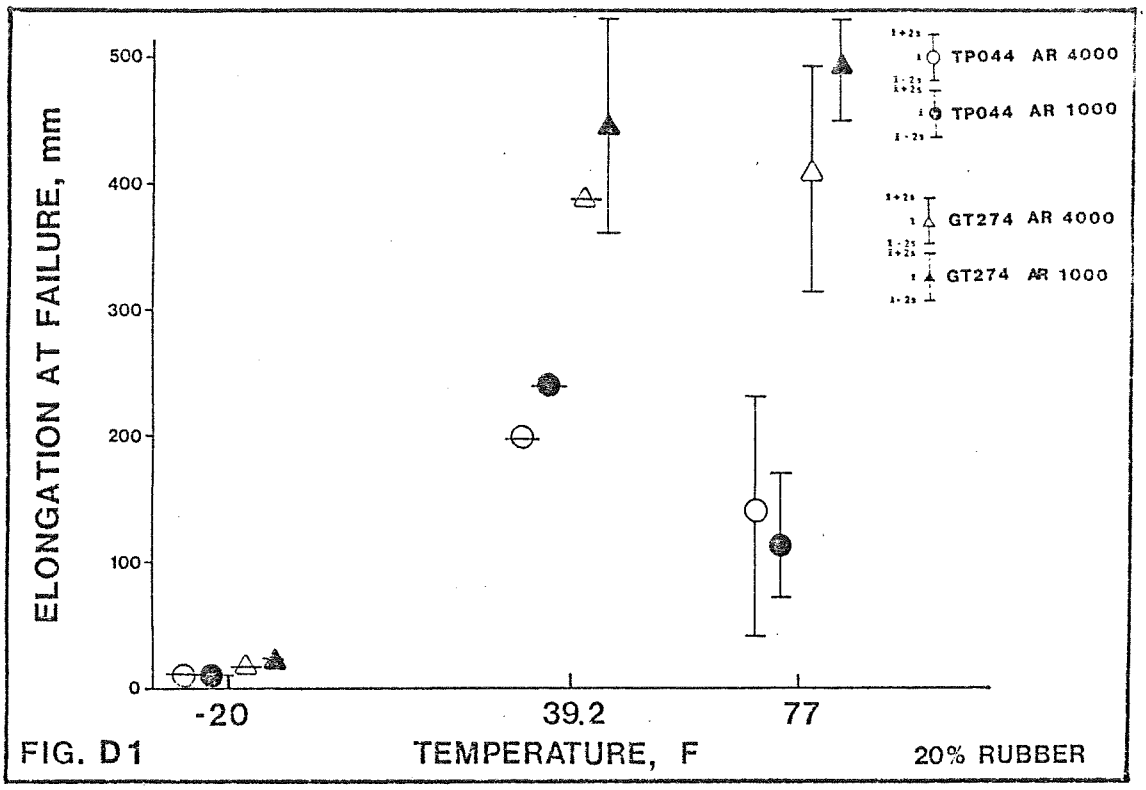


FIG. D1 20% RUBBER

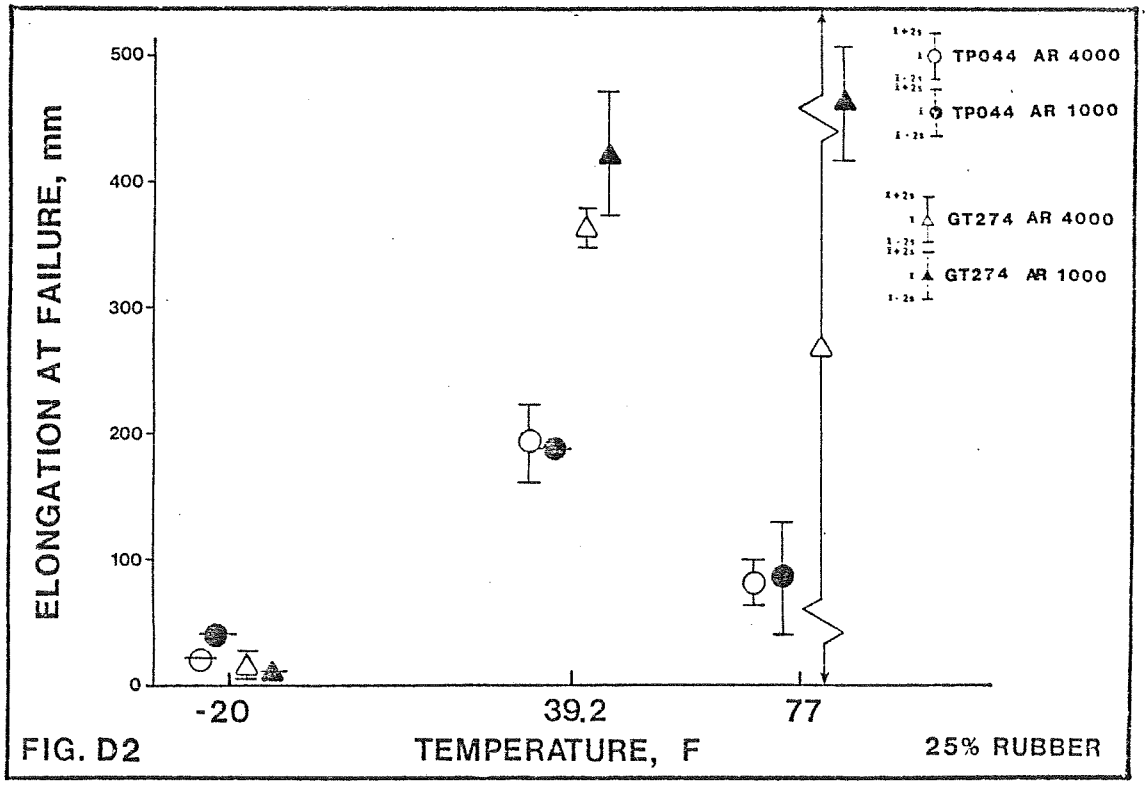


FIG. D2 25% RUBBER

# APPENDIX E

# FORCE-DUCTILITY ENGINEERING

# STRESS AT FAILURE

Table E-1 Engineering Stress at Failure, psi

a. Calculated Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 3.8 | 2.7 | 144.0 | 113.4 | 258.3 | 515.4 |
| | | 4.5 | 3.2 | 135.1 | 118.6 | 302.0 | 528.9 |
| | | 3.8 | 2.8 | 117.4 | 118.5 | 150.7 | 481.8 |
| | | 4.0 | 4.2 | 135.3 | 124.7 | 312.1 | 365.9 |
| | | 4.0 | 4.0 | 130.6 | 121.3 | 288.5 | 412.9 |
| | | 4.2 | 3.7 | 124.3 | 114.1 | 305.4 | 480.2 |
| | 25% | 5.5 | 4.2 | 148.2 | 113.6 | 244.8 | 360.8 |
| | | 4.8 | 3.0 | 146.7 | 118.3 | 275.1 | 523.9 |
| | | 5.7 | 4.7 | 133.1 | 120.1 | 261.7 | |
| | | 5.0 | 4.2 | 145.0 | 120.6 | 298.6 | 500.3 |
| | | 4.8 | 4.0 | 138.3 | 121.3 | 271.7 | 389.4 |
| | | 5.5 | 4.2 | 118.0 | 118.6 | 345.7 | 473.4 |
| AR1000 | 20% | 2.8 | 3.0 | 57.9 | 69.2 | 288.5 | 540.7 |
| | | 2.8 | 2.1 | 83.0 | 66.2 | 147.4 | 540.7 |
| | | 2.8 | 2.8 | 63.2 | 67.5 | 228.0 | 591.1 |
| | | 2.8 | 4.7 | 86.2 | 62.5 | 265.0 | 348.4 |
| | | 3.0 | 3.2 | 79.6 | 64.2 | 278.5 | 482.7 |
| | | 3.0 | 2.8 | 75.6 | 68.2 | 345.7 | 456.6 |
| | 25% | 4.8 | 4.0 | 107.4 | 79.1 | 359.1 | 288.5 |
| | | 4.3 | 3.2 | 116.8 | 78.6 | 339.0 | * |
| | | 5.5 | 2.8 | 126.5 | 86.5 | 349.1 | * |
| | | 4.5 | 3.2 | 101.3 | 84.8 | 382.7 | 465.4 |
| | | 4.5 | 3.2 | 102.3 | 87.5 | 201.1 | * |
| | | 4.2 | 2.8 | 88.7 | 79.1 | 362.5 | * |

*Note: Specimens fractured before readings could be taken.

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 4.05 | 3.43 | 131.12 | 118.43 | 269.5 | 464.18 |
| | | s | .267 | .628 | 9.319 | 4.281 | 61.253 | 62.718 |
| | | cv | 6.58 | 18.30 | 7.11 | 3.62 | 22.73 | 13.51 |
| | 25% | $\bar{x}$ | 5.22 | 4.05 | 138.22 | 118.75 | 282.93 | 449.6 |
| | | s | .397 | .565 | 11.424 | 2.775 | 35.434 | 71.005 |
| | | cv | 7.61 | 13.95 | 8.27 | 2.34 | 12.52 | 15.79 |
| AR1000 | 20% | $\bar{x}$ | 2.87 | 3.10 | 74.25 | 66.30 | 258.85 | 499.37 |
| | | s | .103 | .867 | 11.307 | 2.542 | 66.662 | 73.697 |
| | | cv | 3.60 | 27.97 | 15.23 | 3.84 | 25.75 | 14.78 |
| | 25% | $\bar{x}$ | 4.63 | 3.20 | 107.17 | 82.83 | 332.25 | 376.95 |
| | | s | .472 | .438 | 13.159 | 4.311 | 65.895 | 156.733 |
| | | cv | 10.18 | 13.69 | 12.28 | 5.20 | 19.83 | 41.58 |

Table E-2 Engineering Stress at Failure, psi

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 4.0 | 2.9 | 132.2 | 116.8 | 237.0 | 508.7 |
| | | 4.1 | 4.0 | 130.1 | 120.0 | 302.0 | 419.7 |
| | 25% | 5.3 | 4.0 | 142.7 | 117.3 | 260.5 | 442.4 |
| | | 5.1 | 4.1 | 133.8 | 120.2 | 305.3 | 454.4 |
| AR1000 | 20% | 2.8 | 2.6 | 68.0 | 67.6 | 221.3 | 557.5 |
| | | 3.0 | 3.6 | 80.5 | 65.0 | 296.4 | 429.2 |
| | 25% | 4.9 | 3.3 | 116.9 | 81.4 | 349.1 | 288.5 |
| | | 4.4 | 3.1 | 97.4 | 83.8 | 315.4 | 465.4 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 4.1 | 3.5 | 131.2 | 118.4 | 269.5 | 464.2 |
| | | s | .1 | 1.0 | 1.9 | 2.8 | 57.6 | 78.9 |
| | | cv | 2.2 | 28.2 | 1.4 | 2.4 | 21.4 | 17.0 |
| | 25% | $\bar{x}$ | 5.2 | 4.1 | 138.3 | 118.8 | 282.9 | 448.4 |
| | | s | .2 | .1 | 7.9 | 2.6 | 39.7 | 10.6 |
| | | cv | 3.4 | 2.2 | 5.7 | 2.2 | 14.0 | 2.4 |
| AR1000 | 20% | $\bar{x}$ | 2.9 | 3.1 | 74.3 | 66.3 | 258.9 | 493.4 |
| | | s | .2 | .9 | 11.1 | 2.3 | 66.5 | 113.7 |
| | | cv | 6.1 | 28.6 | 14.9 | 3.5 | 25.7 | 23.0 |
| | 25% | $\bar{x}$ | 4.7 | 3.2 | 107.2 | 82.6 | 332.3 | 376.9 |
| | | s | .4 | .2 | 17.3 | 2.1 | 29.9 | 156.8 |
| | | cv | 9.5 | 5.5 | 16.1 | 2.6 | 9.0 | 41.6 |

Table E-3 ANOVA Summary, Engineering Stress at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 27231.97 | 27231.97 | 18.81 | 4.26 | 7.82 |
| Q | 1 | 18.37 | 18.37 | 0.01 | 4.26 | 7.82 |
| A | 1 | 2783.13 | 2783.13 | 1.92 | 4.26 | 7.82 |
| T | 2 | 1116826.32 | 558413.16 | 385.77 | 3.40 | 5.61 |
| RQ | 1 | 4983.72 | 4983.72 | 3.44 | 4.26 | 7.82 |
| RA | 1 | 543.38 | 543.38 | 0.38 | 4.26 | 7.82 |
| RT | 2 | 76026.50 | 38013.25 | 26.26 | 3.40 | 5.61 |
| QA | 1 | 0.13 | 0.13 | 0.00 | 4.26 | 7.82 |
| QT | 2 | 1302.45 | 651.23 | 0.45 | 3.40 | 5.61 |
| AT | 2 | 4988.22 | 2494.11 | 1.72 | 3.40 | 5.61 |
| RQA | 1 | 2452.45 | 2452.45 | 1.69 | 4.26 | 7.82 |
| RAT | 2 | 1096.94 | 548.47 | 0.38 | 3.40 | 5.61 |
| QAT | 2 | 847.72 | 423.86 | 0.29 | 3.40 | 5.61 |
| RQT | 2 | 7144.04 | 3572.02 | 2.47 | 3.40 | 5.61 |
| RQAT | 2 | 4020.19 | 2010.10 | 1.39 | 3.40 | 5.61 |
| Error | 24 | 34740.56 | 1447.52 | | | |
| TOTAL | 47 | 1285006.16 | | | | |

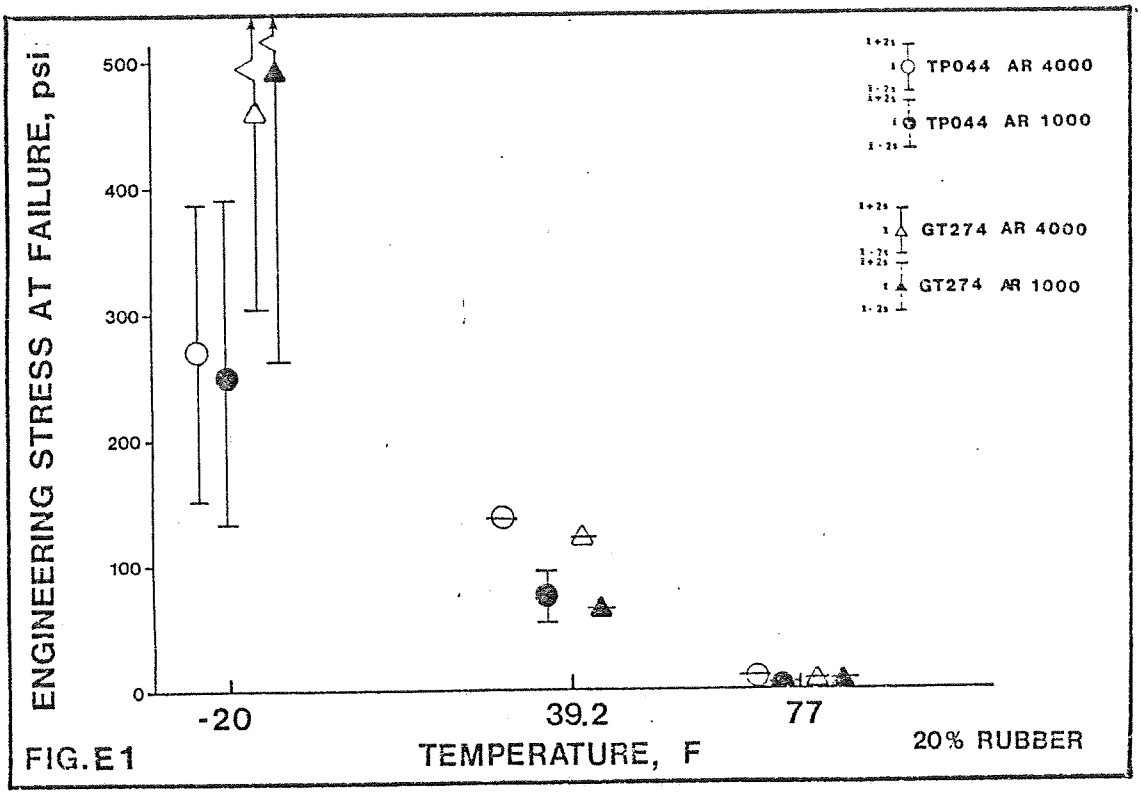
ENGINEERING STRESS AT FAILURE, psi
500
400
300
200
100
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. E1

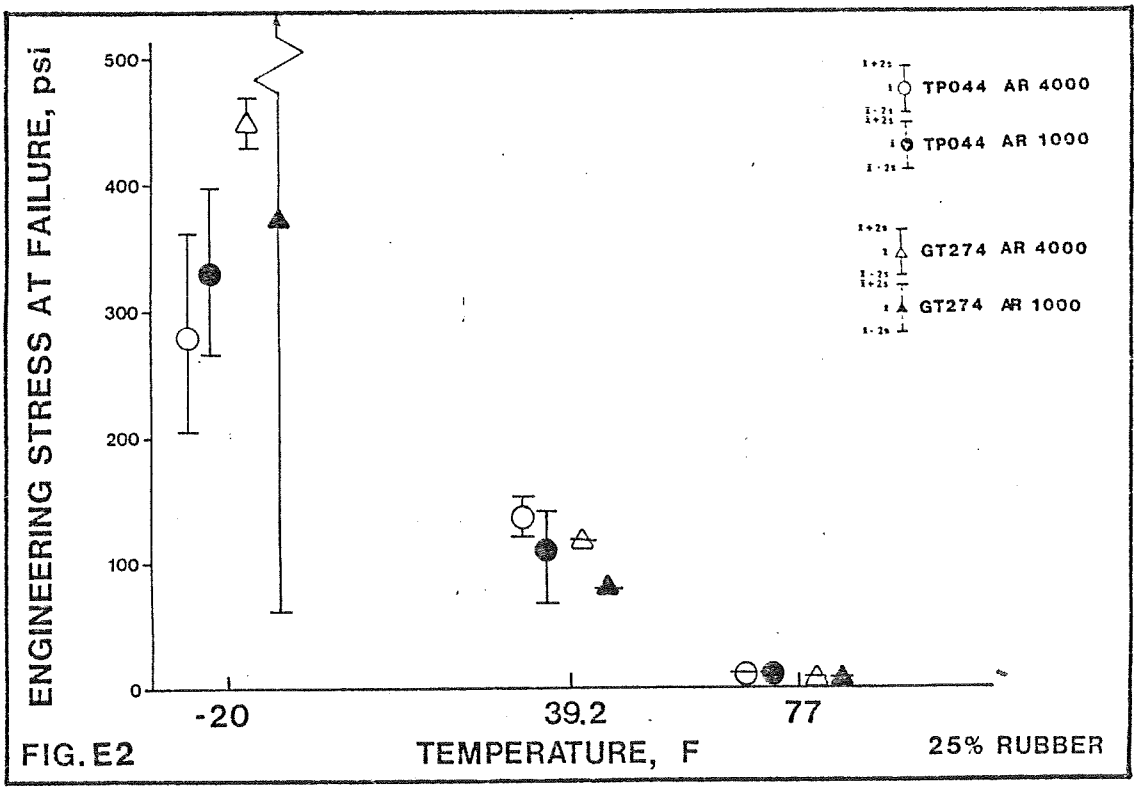
ENGINEERING STRESS AT FAILURE, psi
500
400
300
200
100
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. E2

# APPENDIX F

# FORCE-DUCTILITY ENGINEERING STRAIN AT FAILURE

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

a. Measured Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 2.22 | 8.17 | 3.94 | 7.76 | .22 | .27 |
| | | 2.51 | 7.25 | 3.86 | 7.41 | .31 | .33 |
| | | 2.10 | 9.78 | 3.94 | 7.30 | .37 | .54 |
| | | 2.29 | 7.98 | 3.81 | 7.29 | .42 | .42 |
| | | 4.06 | 5.96 | 3.57 | 7.54 | .34 | .43 |
| | | 3.76 | 9.44 | 3.89 | 8.24 | .25 | .46 |
| | 25% | 2.08 | 4.84 | 3.42 | 7.16 | .33 | .33 |
| | | 1.92 | 1.41 | 3.90 | 6.75 | .39 | .41 |
| | | 1.10 | 3.66 | 3.24 | 7.09 | .42 | |
| | | 1.24 | 9.75 | 3.55 | 7.06 | .46 | .45 |
| | | 1.92 | 9.39 | 3.52 | 7.49 | .37 | .35 |
| | | 1.36 | 8.08 | 3.54 | 6.78 | .31 | .33 |
| AR1000 | 20% | 2.26 | 10.58 | 4.87 | 9.45 | .31 | .40 |
| | | 3.22 | 8.36 | 4.43 | 8.86 | .29 | .40 |
| | | 2.57 | 10.16 | 4.53 | 9.24 | .25 | .34 |
| | | 1.89 | 7.22 | 4.96 | 8.18 | .25 | .37 |
| | | 2.18 | 7.60 | 4.75 | 8.38 | .30 | .41 |
| | | 2.38 | 7.34 | 4.38 | 9.08 | .39 | .42 |
| | 25% | 2.49 | 10.83 | 3.35 | 8.67 | .41 | .35 |
| | | 1.36 | 6.77 | 3.62 | 8.25 | .48 | * |
| | | 2.16 | 8.54 | 4.69 | 8.24 | .33 | * |
| | | 1.38 | 10.40 | 3.50 | 8.02 | .41 | .34 |
| | | 1.46 | 8.65 | 3.81 | 7.81 | .31 | * |
| | | 1.67 | 8.67 | 3.35 | 7.96 | .39 | * |

*Note: Specimens fractured before readings could be taken.

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 2.82 | 8.10 | 3.84 | 7.59 | .32 | .41 |
| | | s | .858 | 1.410 | .139 | .363 | .075 | .096 |
| | | cv | 30.37 | 17.41 | 3.62 | 4.79 | 25.46 | 23.46 |
| | 25% | $\bar{x}$ | 1.60 | 6.19 | 3.53 | 7.06 | .38 | .37 |
| | | s | .418 | 3.393 | .216 | .272 | .056 | .0537 |
| | | cv | 26.05 | 54.83 | 6.13 | 3.86 | 14.70 | 14.35 |
| AR1000 | 20% | $\bar{x}$ | 2.42 | 8.54 | 4.65 | 8.86 | .30 | .39 |
| | | s | .454 | 1.475 | .241 | .490 | .052 | .030 |
| | | cv | 18.76 | 17.27 | 5.18 | 5.53 | 17.28 | 7.61 |
| | 25% | $\bar{x}$ | 1.75 | 8.98 | 3.72 | 8.16 | .39 | .345 |
| | | s | .468 | 1.464 | .506 | .302 | .062 | .009 |
| | | cv | 26.69 | 16.31 | 13.61 | 3.70 | 15.83 | 2.57 |

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

a. Reduced Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 2.28 | 8.40 | 3.91 | 7.49 | .30 | .38 |
| | | 3.37 | 7.79 | 3.76 | 7.69 | .34 | .44 |
| | 25% | 1.70 | 3.30 | 3.52 | 7.00 | .38 | .25 |
| | | 1.51 | 9.07 | 3.54 | 7.11 | .38 | .38 |
| AR1000 | 20% | 2.68 | 9.70 | 4.61 | 9.17 | .28 | .38 |
| | | 2.15 | 7.39 | 4.70 | 8.55 | .31 | .40 |
| | 25% | 2.00 | 8.71 | 3.89 | 8.39 | .41 | .35 |
| | | 1.50 | 9.24 | 3.55 | 7.93 | .37 | .34 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 2.83 | 8.10 | 3.84 | 7.59 | .32 | .41 |
| | | s | .9657 | .5405 | .1329 | .1772 | .0354 | .0532 |
| | | cv | 34.2 | 6.7 | 3.5 | 2.3 | 11.1 | 13.0 |
| | 25% | $\bar{x}$ | 1.61 | 6.19 | 3.53 | 7.06 | .38 | .32 |
| | | s | .1683 | 5.1122 | .0177 | .0975 | 0 | .1152 |
| | | cv | 10.49 | 82.66 | .50 | 1.38 | 0 | 36.57 |
| AR1000 | 20% | $\bar{x}$ | 2.42 | 8.55 | 4.66 | 8.86 | .30 | .39 |
| | | s | .4696 | 2.0467 | .0797 | .5493 | .0266 | .0177 |
| | | cv | 19.4 | 24.0 | 1.7 | 6.2 | 9.0 | 4.5 |
| | 25% | $\bar{x}$ | 1.75 | 8.98 | 3.72 | 8.16 | .39 | .345 |
| | | s | .4430 | .4696 | .3012 | .4076 | .0354 | .009 |
| | | cv | 23.4 | 5.2 | 8.1 | 5.0 | 9.1 | 2.6 |

Table F-3 Log Engineering Strain at Failure, mm/mm

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR40000 | 20% | .3579 | .9243 | .5922 | .8745 | -.5229 | -.4202 |
| | | .5276 | .8915 | .5752 | .8859 | -.4685 | -.3565 |
| | 25% | .2304 | .5185 | .5465 | .8451 | -.4202 | -.6021 |
| | | .1790 | .9576 | .5490 | .8519 | -.4202 | -.4202 |
| AR10000 | 20% | .4281 | .9868 | .6637 | .9624 | -.5528 | -.4202 |
| | | .3324 | .8686 | .6721 | .9320 | -.5086 | -.3979 |
| | 25% | .3010 | .9400 | .5899 | .9238 | -.3872 | -.4559 |
| | | .1761 | .9657 | .5502 | .8993 | -.4318 | -.4685 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR40000 | 20% | $\bar{x}$ | .4428 | .9079 | .5837 | .8802 | -.4957 | -.3884 |
| | | s | .1504 | .0291 | .0151 | .0101 | .0482 | .0564 |
| | | cv | 34.0 | 3.2 | 2.6 | 1.1 | 9.7 | 14.5 |
| | 25% | $\bar{x}$ | .2047 | .7381 | .5478 | .8485 | -.4202 | -.5112 |
| | | s | .0455 | .3890 | .0022 | .0060 | .0000 | .1612 |
| | | cv | 22.3 | 52.7 | .4 | .7 | .0 | 31.5 |
| AR10000 | 20% | $\bar{x}$ | .3803 | .9277 | .6679 | .9116 | -.5307 | -.4091 |
| | | s | .0848 | .1047 | .0074 | .0217 | .0392 | .0198 |
| | | cv | 22.3 | 11.3 | 1.1 | 2.4 | 7.4 | 4.8 |
| | 25% | $\bar{x}$ | .2386 | .9529 | .5701 | .9472 | .4095 | .4622 |
| | | s | .1107 | .0228 | .0352 | .0269 | .0395 | .0112 |
| | | cv | 46.4 | 2.4 | 6.2 | 2.8 | 9.6 | 2.4 |

Table F-4 ANOVA Summary, Log Engineering Strain at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 1.05812 | 1.05812 | 162.16 | 4.26 | 7.82 |
| Q | 1 | .04137 | .04137 | 6.34 | 4.26 | 7.82 |
| A | 1 | .01659 | .01659 | 2.54 | 4.26 | 7.82 |
| T | 2 | 13.67398 | 6.83699 | 1047.80 | 3.40 | 5.61 |
| RQ | 1 | .00042 | .00042 | 0.06 | 4.26 | 7.82 |
| RA | 1 | .00958 | .00958 | 1.47 | 4.26 | 7.82 |
| RT | 2 | .59145 | .29573 | 45.32 | 3.40 | 5.61 |
| QA | 1 | .00970 | .00970 | 1.49 | 4.26 | 7.82 |
| QT | 2 | .03754 | .01877 | 2.88 | 3.40 | 5.61 |
| AT | 2 | .00798 | .00399 | 0.61 | 3.40 | 5.61 |
| RQA | 1 | .00273 | .00273 | 0.42 | 4.26 | 7.82 |
| RAT | 2 | .00854 | .00427 | 0.65 | 3.40 | 5.61 |
| QAT | 2 | .01598 | .00799 | 1.22 | 3.40 | 5.61 |
| RQT | 2 | .04925 | .02463 | 3.77 | 3.40 | 5.61 |
| RQAT | 2 | .00071 | .00036 | 0.05 | 3.40 | 5.61 |
| Error | 24 | .15660 | .00653 | | | |
| TOTAL | 47 | 15.68054 | | | | |

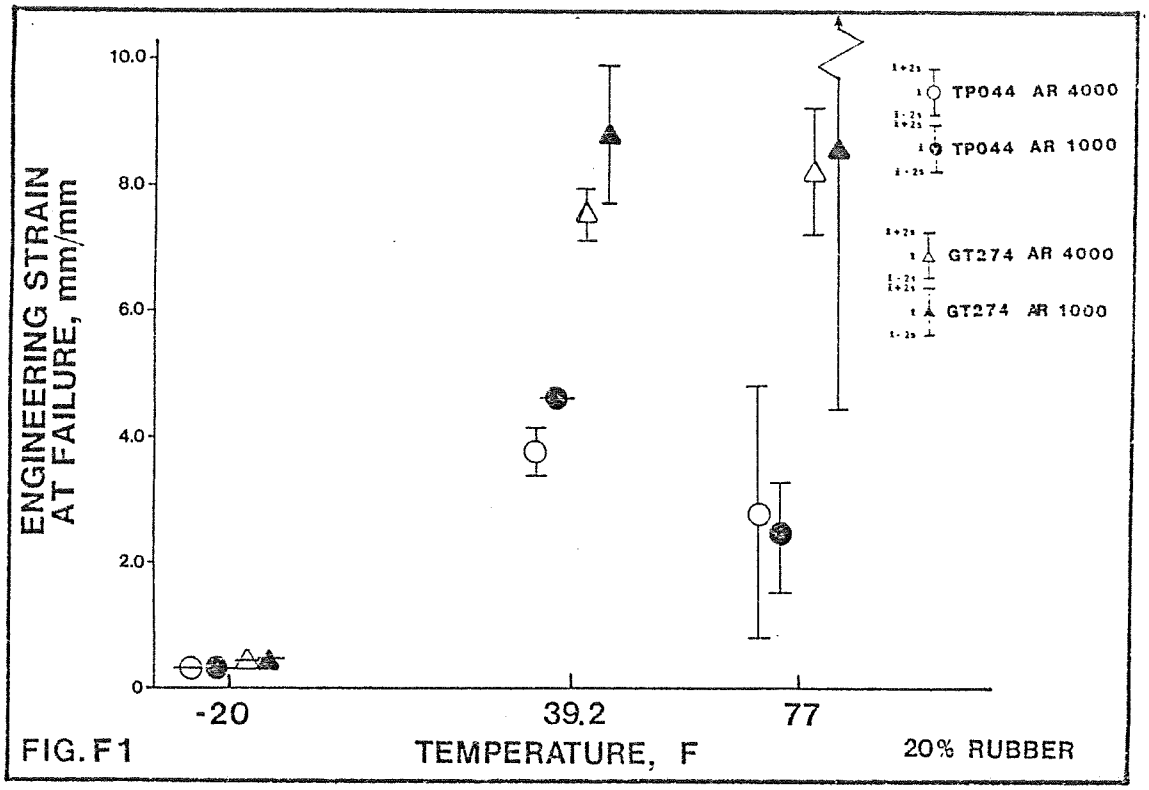
ENGINEERING STRAIN
AT FAILURE, mm/mm
10.0
8.0
6.0
4.0
2.0
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. F1

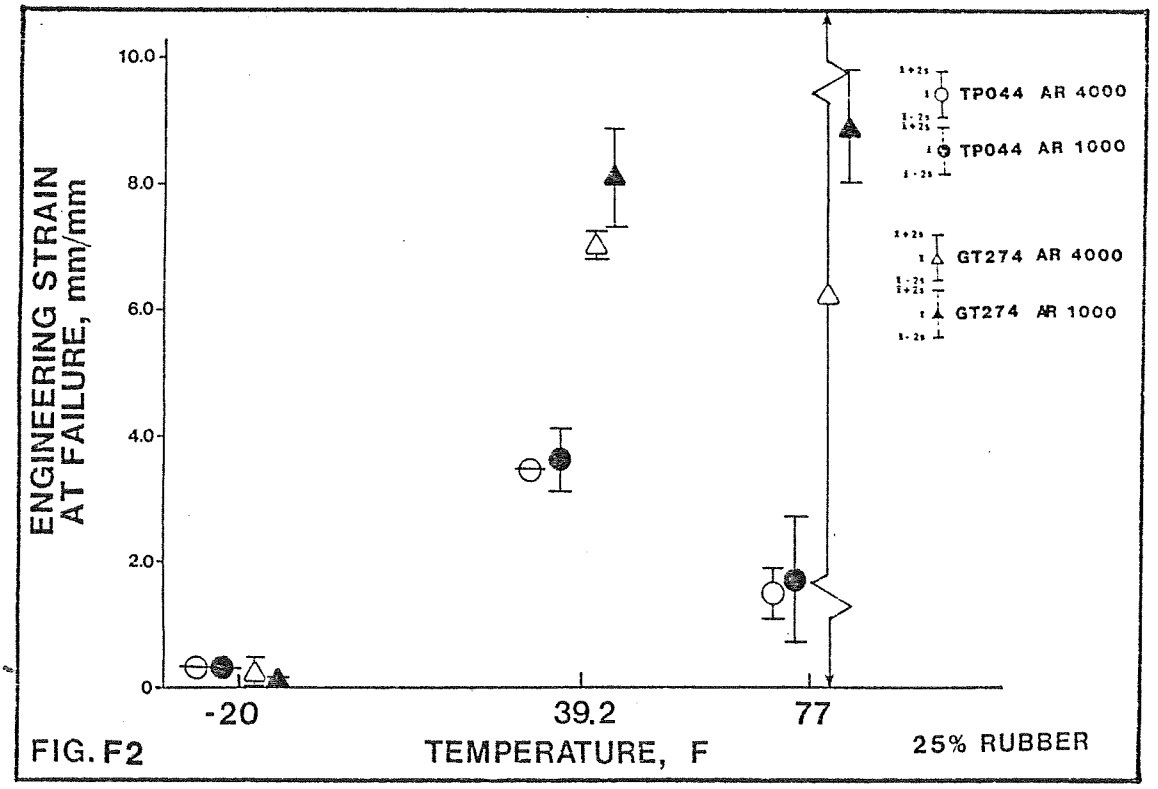
ENGINEERING STRAIN
AT FAILURE, mm/mm
10.0
8.0
6.0
4.0
2.0
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. F2

# APPENDIX G

## FORCE-DUCTILITY TRUE STRESS AT FAILURE

Table G-1 True Stress at Failure, psi

a. Calculated Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 12.3 | 24.3 | 711.5 | 993.5 | 315.1 | 655.0 |
| | | 15.8 | 26.0 | 656.6 | 997.8 | 396.7 | 701.6 |
| | | 11.9 | 30.4 | 580.5 | 983.4 | 206.1 | 742.0 |
| | | 13.2 | 37.4 | 650.8 | 1033.0 | 442.1 | 518.3 |
| | | 20.2 | 27.8 | 596.1 | 1035.8 | 386.7 | 591.0 |
| | | 19.8 | 38.2 | 607.9 | 1054.1 | 381.7 | 701.0 |
| | 25% | 17.0 | 24.3 | 655.5 | 926.8 | 324.8 | 478.6 |
| | | 14.1 | 7.2 | 719.3 | 916.7 | 383.0 | 737.1 |
| | | 11.9 | 21.8 | 564.3 | 972.4 | 371.5 | |
| | | 11.2 | 34.2 | 659.7 | 972.1 | 436.0 | 723.9 |
| | | 14.1 | 34.4 | 625.0 | 1030.6 | 371.6 | 524.5 |
| | | 13.0 | 34.7 | 535.3 | 923.4 | 454.1 | 628.0 |
| AR1000 | 20% | 9.2 | 34.6 | 339.9 | 720.8 | 376.9 | 756.9 |
| | | 11.9 | 20.1 | 451.0 | 652.7 | 190.7 | 756.9 |
| | | 10.1 | 31.5 | 349.2 | 691.7 | 285.0 | 792.0 |
| | | 8.1 | 50.2 | 513.7 | 573.6 | 331.3 | 476.4 |
| | | 9.5 | 32.8 | 457.5 | 602.1 | 362.0 | 679.1 |
| | | 10.1 | 25.6 | 406.5 | 689.0 | 481.3 | 646.9 |
| | 25% | 16.9 | 47.3 | 466.6 | 765.4 | 505.7 | 388.7 |
| | | 10.2 | 24.5 | 539.8 | 727.6 | 501.9 | * |
| | | 17.4 | 26.9 | 720.2 | 802.6 | 465.4 | * |
| | | 10.7 | 36.0 | 455.9 | 774.2 | 538.9 | 623.6 |
| | | 11.1 | 30.4 | 492.3 | 770.9 | 263.0 | * |
| | | 11.1 | 27.2 | 385.5 | 709.0 | 504.7 | * |

*Note: Specimens fractured before readings could be taken.

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 15.5 | 30.7 | 633.9 | 1016.3 | 354.7 | 651.5 |
| | | s | 3.72 | 5.88 | 48.54 | 28.40 | 83.43 | 83.15 |
| | | cv | 23.94 | 19.15 | 7.66 | 2.79 | 23.52 | 12.76 |
| | 25% | $\bar{x}$ | 13.6 | 26.1 | 626.5 | 957.0 | 390.2 | 618.4 |
| | | s | 2.05 | 10.84 | 67.44 | 43.70 | 47.34 | 115.84 |
| | | cv | 15.14 | 41.53 | 10.77 | 4.57 | 12.13 | 18.7? |
| AR1000 | 20% | $\bar{x}$ | 9.8 | 32.5 | 419.6 | 655.0 | 337.9 | 684.7 |
| | | s | 1.26 | 10.20 | 67.46 | 57.03 | 97.13 | 115.58 |
| | | cv | 12.83 | 31.42 | 16.08 | 8.71 | 28.75 | 16.88 |
| | 25% | $\bar{x}$ | 12.9 | 32.1 | 510.1 | 758.3 | 463.3 | 506.2 |
| | | s | 3.31 | 8.46 | 114.63 | 34.05 | 100.84 | 208.12 |
| | | cv | 25.68 | 26.40 | 22.47 | 4.49 | 21.77 | 41.12 |

Table G-2 True Stress at Failure, psi

a. Reduced Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 13.3 | 26.9 | 649.53 | 991.57 | 306.0 | 699.5 |
| | | 17.7 | 34.5 | 618.27 | 1040.97 | 403.5 | 603.4 |
| | 25% | 14.3 | 17.8 | 646.37 | 938.63 | 359.8 | 607.9 |
| | | 12.8 | 34.4 | 606.67 | 975.37 | 420.6 | 625.5 |
| AR1000 | 20% | 10.4 | 28.7 | 380.03 | 688.40 | 284.2 | 768.6 |
| | | 9.2 | 36.2 | 459.23 | 621.57 | 391.5 | 600.8 |
| | 25% | 14.8 | 32.9 | 575.53 | 765.20 | 491.0 | 388.7 |
| | | 11.0 | 31.2 | 444.57 | 751.37 | 435.5 | 623.6 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 15.5 | 30.7 | 633.9 | 1016.3 | 354.8 | 651.5 |
| | | s | 3.90 | 6.73 | 27.70 | 43.77 | 86.39 | 85.15 |
| | | cv | 25.2 | 21.9 | 4.4 | 4.3 | 24.4 | 13.1 |
| | 25% | $\bar{x}$ | 13.6 | 26.1 | 626.5 | 957.0 | 390.2 | 616.7 |
| | | s | 1.33 | 14.71 | 35.17 | 32.6 | 53.9 | 15.6 |
| | | cv | 9.8 | 56.4 | 5.6 | 3.4 | 13.8 | 2.5 |
| AR1000 | 20% | $\bar{x}$ | 9.8 | 32.5 | 419.63 | 655.0 | 337.9 | 684.7 |
| | | s | 1.06 | 6.65 | 70.17 | 59.21 | 95.07 | 148.67 |
| | | cv | 10.8 | 20.5 | 16.7 | 9.0 | 28.1 | 21.7 |
| | 25% | $\bar{x}$ | 12.9 | 32.1 | 510.1 | 758.3 | 463.4 | 506.2 |
| | | s | 3.37 | 1.51 | 116.03 | 12.25 | 49.17 | 208.12 |
| | | cv | 26.1 | 4.7 | 22.8 | 1.6 | 10.6 | 41.1 |

Table G-3 Log True Stress at Failure, psi

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 1.1239 | 1.4298 | 2.8126 | 2.9963 | 2.4857 | 2.8448 |
| | | 1.2480 | 1.5378 | 2.7912 | 3.0174 | 2.6058 | 2.7806 |
| | 25% | 1.1553 | 1.2504 | 2.8105 | 2.9725 | 2.5561 | 2.7838 |
| | | 1.1072 | 1.5366 | 2.7830 | 2.9892 | 2.6239 | 2.7962 |
| AR1000 | 20% | 1.0170 | 1.4579 | 2.5798 | 2.8378 | 2.4536 | 2.8857 |
| | | .9638 | 1.5587 | 2.6620 | 2.7935 | 2.5927 | 2.7787 |
| | 25% | 1.1703 | 1.5172 | 2.7601 | 2.8838 | 2.6911 | 2.5896 |
| | | 1.0414 | 1.4942 | 2.6479 | 2.8759 | 2.6390 | 2.7949 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 1.1860 | 1.4838 | 2.8019 | 3.0069 | 2.5458 | 2.8127 |
| | | s | .1100 | .0957 | .0190 | .0187 | .1064 | .0569 |
| | | cv | 9.3 | 6.4 | .7 | .6 | 4.2 | 2.0 |
| | 25% | $\bar{x}$ | 1.1313 | 1.3935 | 2.7968 | 2.9809 | 2.5900 | 2.7900 |
| | | s | .0426 | .2536 | .0244 | .0148 | .0601 | .0110 |
| | | cv | 3.8 | 18.2 | .9 | .5 | 2.3 | .4 |
| AR1000 | 20% | $\bar{x}$ | .9904 | 1.5083 | 2.6209 | 2.8157 | 2.5232 | 2.8322 |
| | | s | .0471 | .0893 | .0728 | .0392 | .1232 | .0948 |
| | | cv | 4.8 | 5.9 | 2.8 | 1.4 | 4.9 | 3.4 |
| | 25% | $\bar{x}$ | 1.1059 | 1.5057 | 2.7040 | 2.8799 | 2.6651 | 2.6923 |
| | | s | .1142 | .0204 | .0994 | .0070 | .0462 | .1819 |
| | | cv | 10.3 | 1.4 | 3.7 | .2 | 1.7 | 6.8 |

Table G-4 ANOVA Summary, Log True Stress at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 0.7700 | 0.7700 | 140.38 | 4.26 | 7.82 |
| Q | 1 | 0.0009 | 0.0009 | 0.18 | 4.26 | 7.82 |
| A | 1 | 0.0379 | 0.0379 | 6.92 | 4.26 | 7.82 |
| T | 2 | 23.0783 | 11.5300 | 2103.70 | 3.40 | 5.61 |
| RQ | 1 | 0.0245 | 0.0245 | 4.48 | 4.26 | 7.82 |
| RA | 1 | 0.0035 | 0.0035 | 0.65 | 4.26 | 7.82 |
| RT | 2 | 0.0081 | 0.0400 | 7.40 | 3.40 | 5.61 |
| QA | 1 | 0.0145 | 0.0145 | 2.65 | 4.26 | 7.82 |
| QT | 2 | 0.0028 | 0.0010 | 0.26 | 3.40 | 5.61 |
| AT | 2 | 0.0437 | 0.0220 | 3.99 | 3.40 | 5.61 |
| RQA | 1 | 0.0073 | 0.0073 | 1.33 | 4.26 | 7.82 |
| RAT | 2 | 0.0327 | 0.0160 | 2.99 | 3.40 | 5.61 |
| QAT | 2 | 0.0102 | 0.0050 | 0.93 | 3.40 | 5.61 |
| RQT | 2 | 0.0121 | 0.0060 | 1.11 | 3.40 | 5.61 |
| RQAT | 2 | 0.0059 | 0.0020 | 0.54 | 3.40 | 5.61 |
| Error | 24 | 0.1316 | 0.0054 | | | |
| TOTAL | 47 | 24.2578 | | | | |

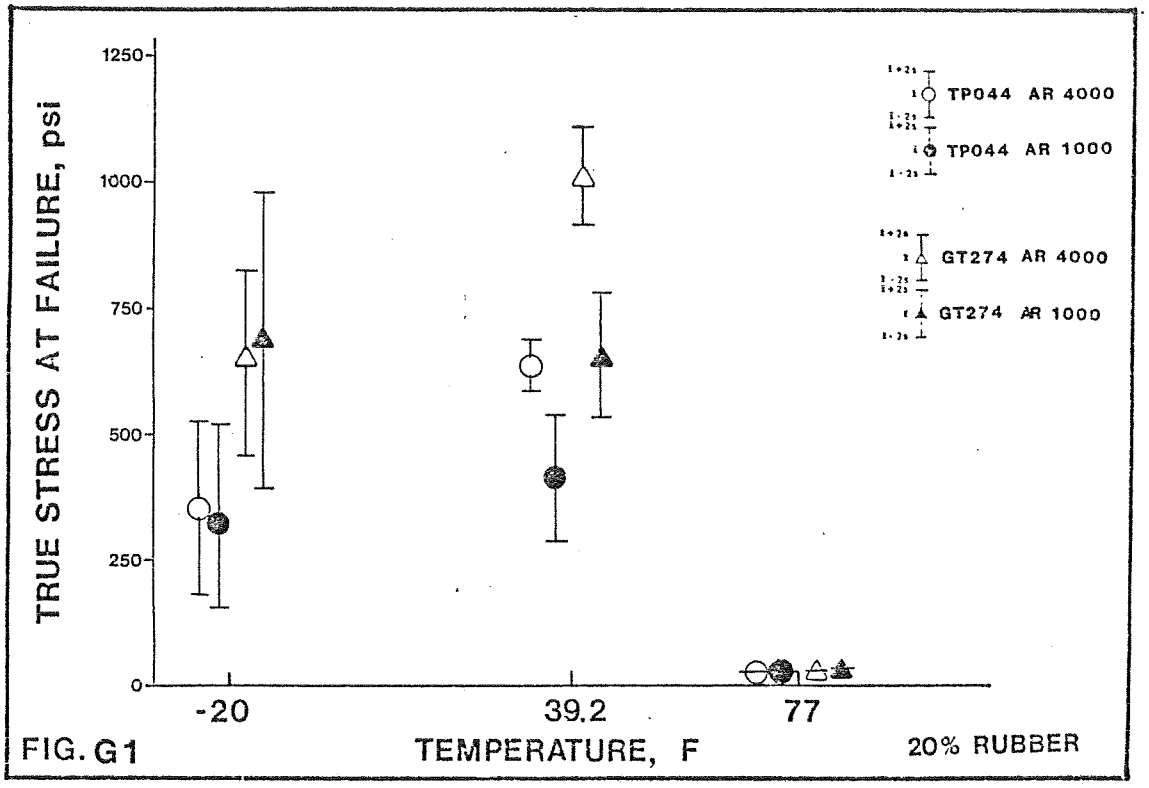
TRUE STRESS AT FAILURE, psi
1250
1000
750
500
250
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. G1

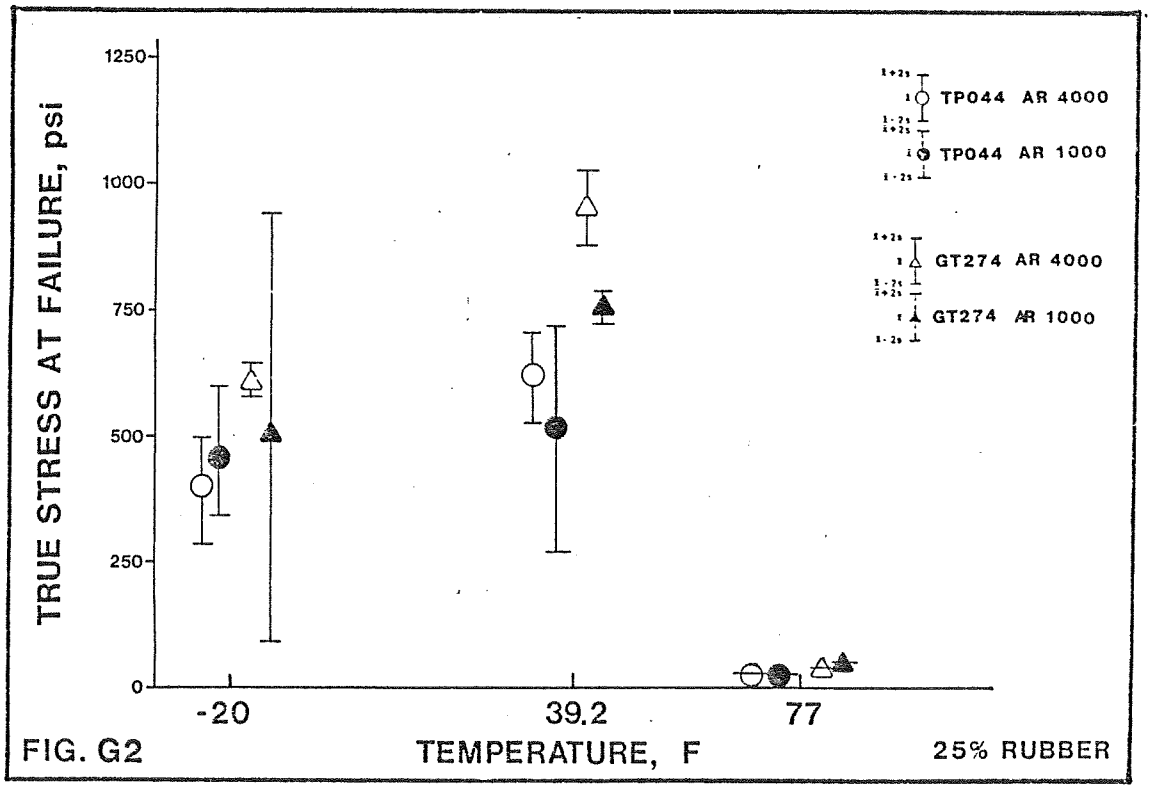
TRUE STRESS AT FAILURE, psi
1250
1000
750
500
250
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. G2

# APPENDIX H

# FORCE-DUCTILITY TRUE STRAIN AT FAILURE

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

a. Measured Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 1.17<br>1.26<br>1.13<br>1.19<br>1.62<br>1.56 | 2.22<br>2.11<br>2.38<br>2.19<br>1.94<br>2.35 | 1.60<br>1.58<br>1.60<br>1.57<br>1.52<br>1.59 | 2.17<br>2.13<br>2.12<br>2.11<br>2.14<br>2.22 | .20<br>.27<br>.31<br>.35<br>.29<br>.22 | .24<br>.28<br>.43<br>.35<br>.36<br>.38 |
| | 25% | 1.12<br>1.07<br>.74<br>.81<br>1.07<br>.86 | 1.77<br>.88<br>1.54<br>2.11<br>2.15<br>2.12 | 1.49<br>1.59<br>1.44<br>1.51<br>1.51<br>1.51 | 2.10<br>2.05<br>2.09<br>2.09<br>2.14<br>2.05 | .28<br>.33<br>.35<br>.38<br>.31<br>.27 | .28<br>.34<br>.37<br>.30<br>.28 |
| AR1000 | 20% | 1.18<br>1.44<br>1.27<br>1.06<br>1.16<br>1.22 | 2.45<br>2.24<br>2.41<br>2.37<br>2.34<br>2.21 | 1.77<br>1.69<br>1.71<br>1.79<br>1.75<br>1.68 | 2.34<br>2.39<br>2.33<br>2.22<br>2.24<br>2.31 | .27<br>.26<br>.22<br>.22<br>.26<br>.33 | .34<br>.34<br>.29<br>.31<br>.34<br>.35 |
| | 25% | 1.25<br>.86<br>1.15<br>.87<br>.90<br>.98 | 2.47<br>2.05<br>2.26<br>2.43<br>2.27<br>2.27 | 1.47<br>1.53<br>1.74<br>1.50<br>1.57<br>1.47 | 2.27<br>2.23<br>2.22<br>2.20<br>2.18<br>2.19 | .34<br>.39<br>.29<br>.34<br>.27<br>.33 | .30<br>.29 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 1.32 | 2.20 | 1.58 | 2.15 | .27 | .34 |
| | | s | .213 | .162 | .030 | .041 | .056 | .069 |
| | | cv | 16.11 | 7.37 | 1.91 | 1.90 | 20.52 | 20.29 |
| | 25% | $\bar{x}$ | .95 | 1.76 | 1.51 | 2.09 | .32 | .31 |
| | | s | .161 | .495 | .048 | .034 | .042 | .040 |
| | | cv | 17.02 | 28.12 | 3.21 | 1.62 | 13.11 | 12.66 |
| AR1000 | 20% | $\bar{x}$ | 1.22 | 2.34 | 1.73 | 2.31 | .26 | .33 |
| | | s | .128 | .095 | .045 | .064 | .041 | .023 |
| | | cv | 10.46 | 4.05 | 2.59 | 2.78 | 15.58 | 7.06 |
| | 25% | $\bar{x}$ | 1.00 | 2.29 | 1.55 | 2.22 | .33 | .295 |
| | | s | .162 | .149 | .102 | .033 | .042 | .009 |
| | | cv | 16.21 | 6.51 | 6.60 | 1.48 | 12.94 | 3.05 |

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

a. Reduced Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 1.19 | 2.24 | 1.59 | 2.14 | .26 | .32 |
| | | 1.46 | 2.16 | 1.56 | 2.16 | .29 | .36 |
| | 25% | .98 | 1.40 | 1.51 | 2.08 | .32 | .21 |
| | | .91 | 2.13 | 1.51 | 2.09 | .32 | .32 |
| AR1000 | 20% | 1.30 | 2.37 | 1.72 | 2.35 | .25 | .32 |
| | | 1.15 | 2.31 | 1.74 | 2.26 | .27 | .33 |
| | 25% | 1.09 | 2.26 | 1.58 | 2.24 | .34 | .30 |
| | | .92 | 2.32 | 1.51 | 2.19 | .31 | .29 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 1.33 | 2.20 | 1.58 | 2.15 | .28 | .34 |
| | | s | .239 | .071 | .027 | .018 | .027 | .035 |
| | | cv | 18.1 | 3.2 | 1.7 | .8 | 9.7 | 10.4 |
| | 25% | $\bar{x}$ | .95 | 1.77 | 1.51 | 2.085 | .32 | .27 |
| | | s | .062 | .647 | 0 | .009 | 0 | .097 |
| | | cv | 6.6 | 36.7 | 0 | .4 | 0 | 36.8 |
| AR1000 | 20% | $\bar{x}$ | 1.23 | 2.34 | 1.73 | 2.31 | .26 | .325 |
| | | s | .133 | .053 | .018 | .080 | .018 | .009 |
| | | cv | 10.9 | 2.3 | 1.0 | 3.5 | 6.8 | 2.7 |
| | 25% | $\bar{x}$ | 1.01 | 2.29 | 1.55 | 2.22 | .33 | .295 |
| | | s | .151 | .053 | .062 | .044 | .027 | .009 |
| | | cv | 15.0 | 2.3 | 4.0 | 2.0 | 8.2 | 3.1 |

Table H-3 Log True Strain at Failure, mm/mm

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .0755 | .3502 | .2014 | .3304 | -.5850 | -.4949 |
| | | .1644 | .3345 | .1931 | .3345 | -.5376 | -.4437 |
| | 25% | -.0088 | .1461 | .1790 | .3181 | -.4949 | -.6778 |
| | | -.0410 | .3284 | .1790 | .3201 | -.4949 | -.4949 |
| AR1000 | 20% | .1139 | .3747 | .2355 | .3711 | -.6021 | -.4949 |
| | | .0607 | .3636 | .2405 | .3541 | -.5686 | -.4815 |
| | 25% | .0374 | .3541 | .1987 | .3502 | -.4685 | -.5229 |
| | | -.0362 | .3655 | .1790 | .3404 | -.5086 | -.5376 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .1200 | .3424 | .1973 | .3325 | -.5613 | -.4693 |
| | | s | .0788 | .0139 | .0074 | .0036 | .0420 | .0454 |
| | | cv | 65.7 | 4.1 | 3.7 | 1.1 | 7.5 | 9.7 |
| | 25% | $\bar{x}$ | -.0249 | .2373 | .1790 | .3191 | -.4949 | -.5864 |
| | | s | .0285 | .1615 | 0 | .0018 | 0 | .1620 |
| | | cv | 144.6 | 68.1 | 0 | .6 | 0 | 27.6 |
| AR1000 | 20% | $\bar{x}$ | .0873 | .3692 | .2380 | .3626 | -.5854 | -.4882 |
| | | s | .0471 | .0098 | .0044 | .0151 | .0297 | .0119 |
| | | cv | 54.0 | 2.7 | 1.9 | 4.2 | 5.1 | 2.4 |
| | 25% | $\bar{x}$ | .0006 | .3598 | .1889 | .3453 | -.4886 | -.5303 |
| | | s | .0652 | .0101 | .0175 | .0087 | .0355 | .0130 |
| | | cv | 10868.3 | 2.8 | 9.2 | 2.5 | 7.3 | 2.5 |

Table H-4 ANOVA Summary, Log True Strain at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | .23248 | .23248 | 125.70 | 4.26 | 7.82 |
| Q | 1 | .01155 | .01155 | 6.24 | 4.26 | 7.82 |
| A | 1 | .00845 | .00845 | 4.57 | 4.26 | 7.82 |
| T | 2 | 6.14100 | 3.07050 | 1660.18 | 3.40 | 5.61 |
| RQ | 1 | .00305 | .00305 | 1.65 | 4.26 | 7.82 |
| RA | 1 | .00376 | .00376 | 2.03 | 4.26 | 7.82 |
| RT | 2 | .12777 | .06389 | 34.54 | 3.40 | 5.61 |
| QA | 1 | .00438 | .00438 | 2.37 | 4.26 | 7.82 |
| QT | 2 | .01107 | .00554 | 2.99 | 3.40 | 5.61 |
| AT | 2 | .00414 | .00207 | 1.12 | 3.40 | 5.61 |
| RQA | 1 | .00029 | .00029 | 0.16 | 4.26 | 7.82 |
| RAT | 2 | .00214 | .00107 | 0.58 | 3.40 | 5.61 |
| QAT | 2 | .00590 | .00295 | 1.60 | 3.40 | 5.61 |
| RQT | 2 | .02579 | .01290 | 6.97 | 3.40 | 5.61 |
| RQAT | 2 | .00064 | .00032 | 0.17 | 3.40 | 5.61 |
| Error | 24 | .04439 | .00185 | | | |
| TOTAL | 47 | 6.62675 | | | | |

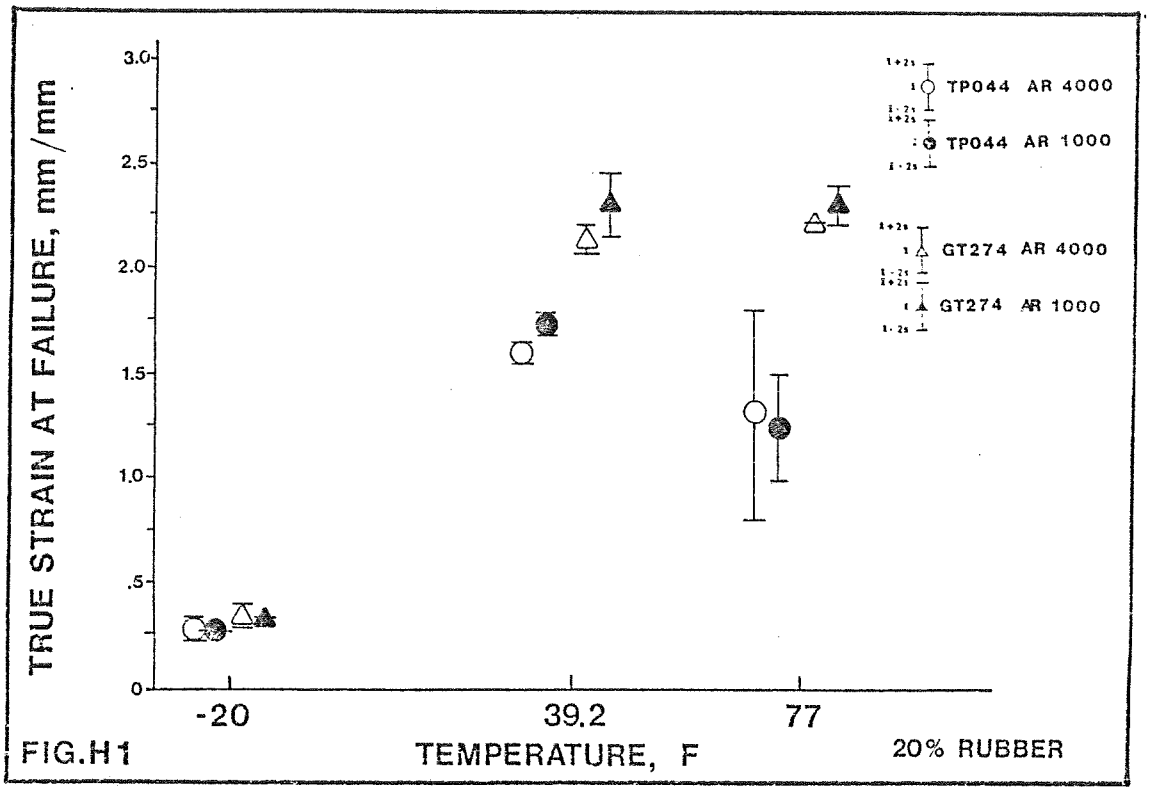
TRUE STRAIN AT FAILURE, mm/mm
3.0
2.5
2.0
1.5
1.0
.5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG.H1

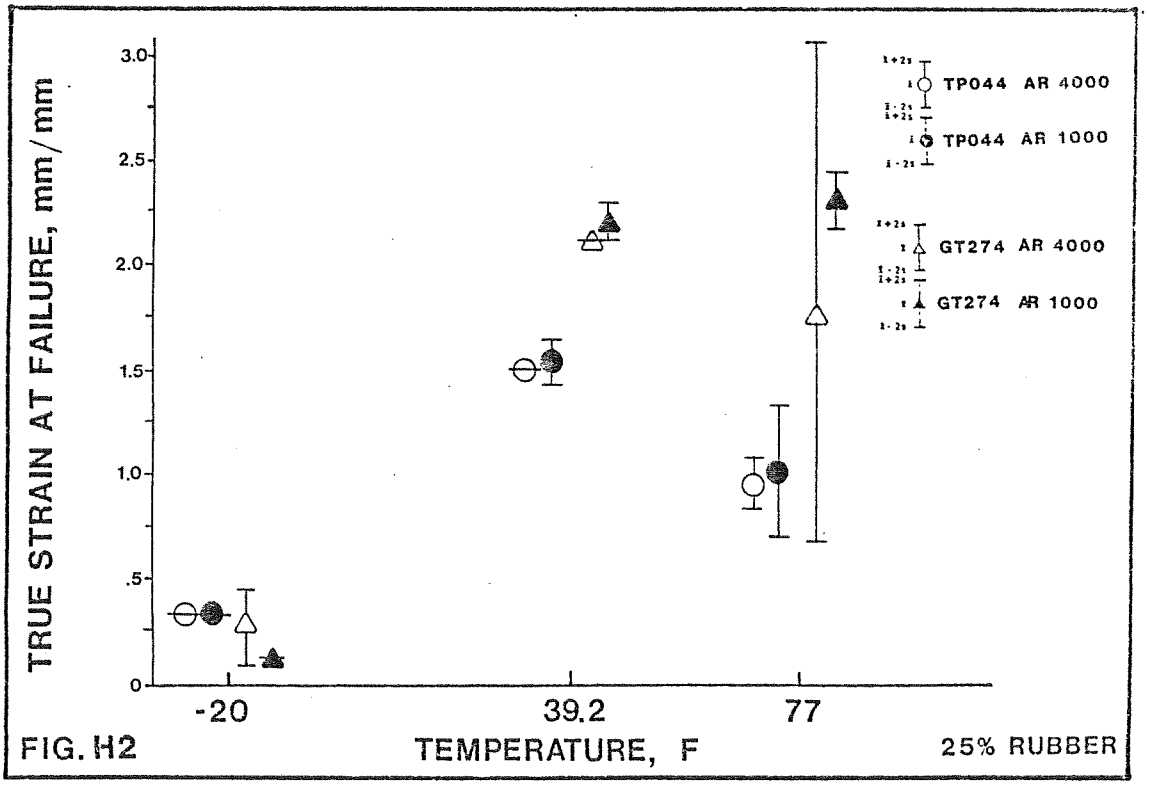
TRUE STRAIN AT FAILURE, mm/mm
3.0
2.5
2.0
1.5
1.0
.5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. H2

# APPENDIX I

## FORCE-DUCTILITY ENGINEERING

## CREEP COMPLIANCE

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

a. Calculated Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .5801 | 3.0822 | .0274 | .068 | .0009 | .0005 |
| | | .558 | 2.2980 | .0286 | .063 | .0010 | .0006 |
| | | .548 | 3.4712 | .0336 | .062 | .0024 | .0011 |
| | | .574 | 1.9166 | .0282 | .0584 | .0013 | .0011 |
| | | 1.016 | 1.4918 | .0273 | .0621 | .0012 | .0010 |
| | | .902 | 2.5805 | .0313 | .0722 | .0008 | .0010 |
| | 25% | .378 | 1.1633 | .0231 | .0630 | .0013 | .0009 |
| | | .397 | .4727 | .0266 | .0571 | .0014 | .0008 |
| | | .194 | .7841 | .0244 | .0591 | .0016 | |
| | | .248 | 1.7342 | .0245 | .0584 | .0015 | .0009 |
| | | .397 | 1.9022 | .0254 | .0618 | .0014 | .0009 |
| | | .247 | 1.7630 | .0300 | .0572 | .0009 | .0007 |
| AR1000 | 20% | .8018 | 3.5412 | .0840 | .136 | .0011 | .0007 |
| | | 1.1408 | 3.8965 | .0534 | .134 | .0020 | .0007 |
| | | .9113 | 3.6056 | .0717 | .137 | .0011 | .0006 |
| | | .6694 | 2.0889 | .0576 | .131 | .0009 | .0011 |
| | | .730 | 2.9770 | .0596 | .131 | .0011 | .0008 |
| | | .797 | 2.8660 | .0579 | .133 | .0011 | .0009 |
| | 25% | .515 | 2.7107 | .0312 | .110 | .0011 | .0012 |
| | | .314 | 2.1470 | .0310 | .105 | .0014 | |
| | | .392 | 3.0297 | .0371 | .0949 | .0010 | |
| | | .307 | 3.2965 | .0346 | .093 | .0011 | .0007 |
| | | .325 | 2.7412 | .0373 | .089 | .0015 | |
| | | .402 | 3.0746 | .0377 | .101 | .0011 | |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .6964 | 2.4734 | .0294 | .0643 | .0127 | .0009 |
| | | s | .2069 | .7324 | .0025 | .0050 | .0006 | .0003 |
| | | cv | 29.72 | 29.61 | 8.57 | 7.71 | 46.21 | 29.88 |
| | 25% | $\bar{x}$ | .3102 | 1.3033 | .0257 | .0595 | .0014 | .0008 |
| | | s | .0906 | .5890 | .0024 | .0024 | .0024 | .0009 |
| | | cv | 29.21 | 45.20 | 9.43 | 4.10 | 17.99 | 10.65 |
| AR1000 | 20% | $\bar{x}$ | .8417 | 3.1625 | .0640 | .1337 | .0012 | .0008 |
| | | s | .1674 | .6563 | .0116 | .0025 | .0004 | .0002 |
| | | cv | 19.88 | 20.75 | 18.07 | 1.87 | 32.22 | 22.36 |
| | 25% | $\bar{x}$ | .3758 | 2.8333 | .0341 | .0988 | .0012 | .0010 |
| | | s | .0793 | .4015 | .0031 | .0079 | .0002 | .0004 |
| | | cv | 21.11 | 14.17 | 8.84 | 8.02 | 16.67 | 46.63 |

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

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .562 | 2.950 | .0299 | .064 | .0014 | .0008 |
| | | .831 | 1.996 | .0289 | .064 | .0011 | .0010 |
| | 25% | .323 | .807 | .0247 | .0597 | .0013 | .0008 |
| | | .297 | 1.800 | .0266 | .0591 | .0011 | .0007 |
| AR1000 | 20% | .951 | 3.681 | .0697 | .1360 | .0013 | .0007 |
| | | .732 | 2.644 | .0584 | .1320 | .0010 | .0009 |
| | 25% | .407 | 2.629 | .0331 | .103 | .0012 | .0012 |
| | | .345 | 3.037 | .0365 | .097 | .0012 | .0007 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .697 | 2.473 | .0294 | .064 | .0013 | .0009 |
| | | s | .238 | .845 | .0009 | 0 | .0003 | .0002 |
| | | cv | 34.2 | 34.2 | 3.0 | 0 | 21.3 | 19.7 |
| | 25% | $\bar{x}$ | .310 | 1.304 | .0257 | .0594 | .0012 | .0008 |
| | | s | .023 | .880 | .0016 | .0005 | .0002 | .0001 |
| | | cv | 7.4 | 67.5 | 6.6 | .9 | 14.8 | 11.8 |
| AR1000 | 20% | $\bar{x}$ | .8415 | 3.163 | .0641 | .1340 | .0012 | .0008 |
| | | s | .1940 | .919 | .0100 | .0035 | .0003 | .0002 |
| | | cv | 23.1 | 29.1 | 15.6 | 2.6 | 23.1 | 22.2 |
| | 25% | $\bar{x}$ | .376 | 2.833 | .0348 | .0985 | .0012 | .0010 |
| | | s | .055 | .362 | .0030 | .0080 | 0 | .0004 |
| | | cv | 14.6 | 12.8 | 8.7 | 8.1 | 0 | 46.6 |

Table I-3 ANOVA Summary, Engineering Creep Compliance at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 5.0053 | 5.0053 | 73.63 | 4.26 | 7.82 |
| Q | 1 | 0.4890 | 0.4890 | 7.19 | 4.26 | 7.82 |
| A | 1 | 0.5565 | 0.5565 | 8.19 | 4.26 | 7.82 |
| T | 2 | 22.9882 | 11.4940 | 169.08 | 3.40 | 5.61 |
| RQ | 1 | 0.0354 | 0.0354 | 0.52 | 4.26 | 7.82 |
| RA | 1 | 0.3588 | 0.3588 | 5.28 | 4.26 | 7.82 |
| RT | 2 | 9.2480 | 4.6200 | 68.02 | 3.40 | 5.61 |
| QA | 1 | 0.0415 | 0.0415 | 0.61 | 4.26 | 7.82 |
| QT | 2 | 0.8939 | 0.4460 | 6.58 | 3.40 | 5.61 |
| AT | 2 | 0.9255 | 0.4630 | 6.81 | 3.40 | 5.61 |
| RQA | 1 | 0.0698 | 0.0698 | 1.03 | 4.26 | 7.82 |
| RAT | 2 | 0.6503 | 0.3250 | 4.78 | 3.40 | 5.61 |
| QAT | 2 | 0.1039 | 0.0520 | 0.76 | 3.40 | 5.61 |
| RQT | 2 | 0.0691 | 0.0350 | 0.51 | 3.40 | 5.61 |
| RQAT | 2 | 0.1413 | 0.0700 | 1.04 | 3.40 | 5.61 |
| Error | 24 | 1.6315 | 0.0679 | | | |
| TOTAL | 47 | 43.2089 | | | | |

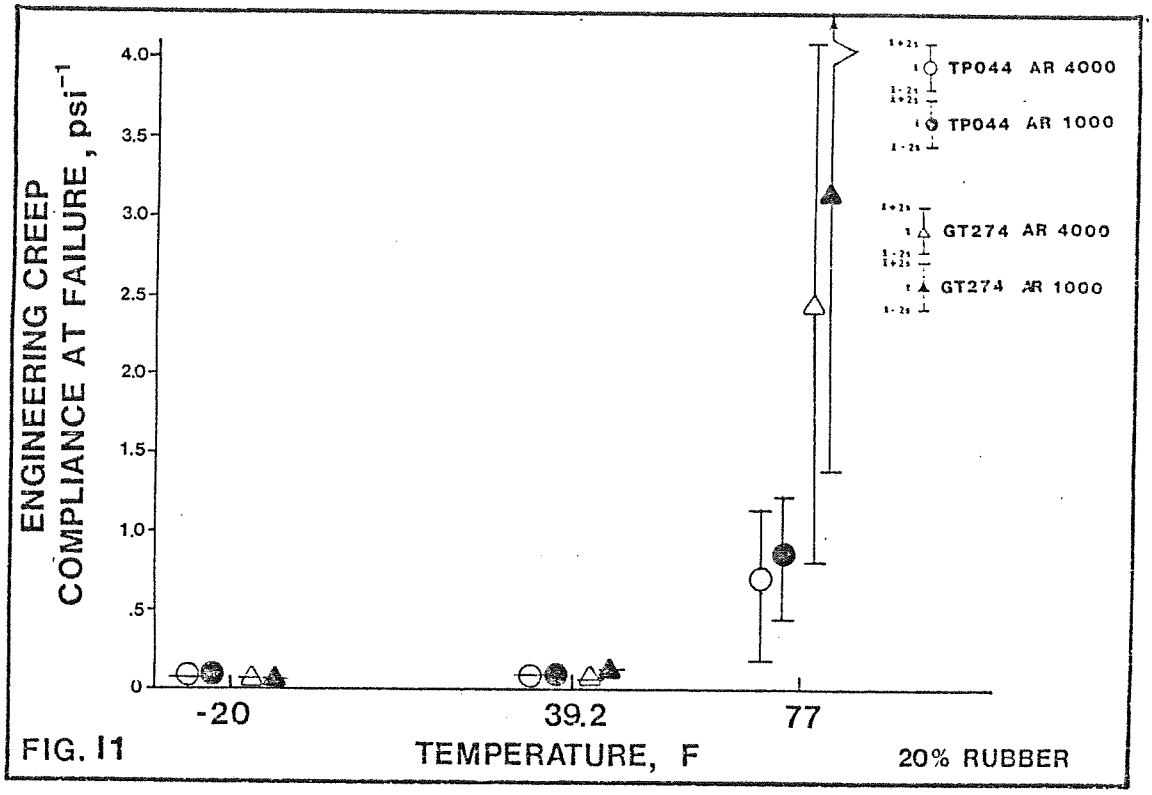
ENGINEERING CREEP COMPLIANCE AT FAILURE, psi$^{-1}$
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. I1

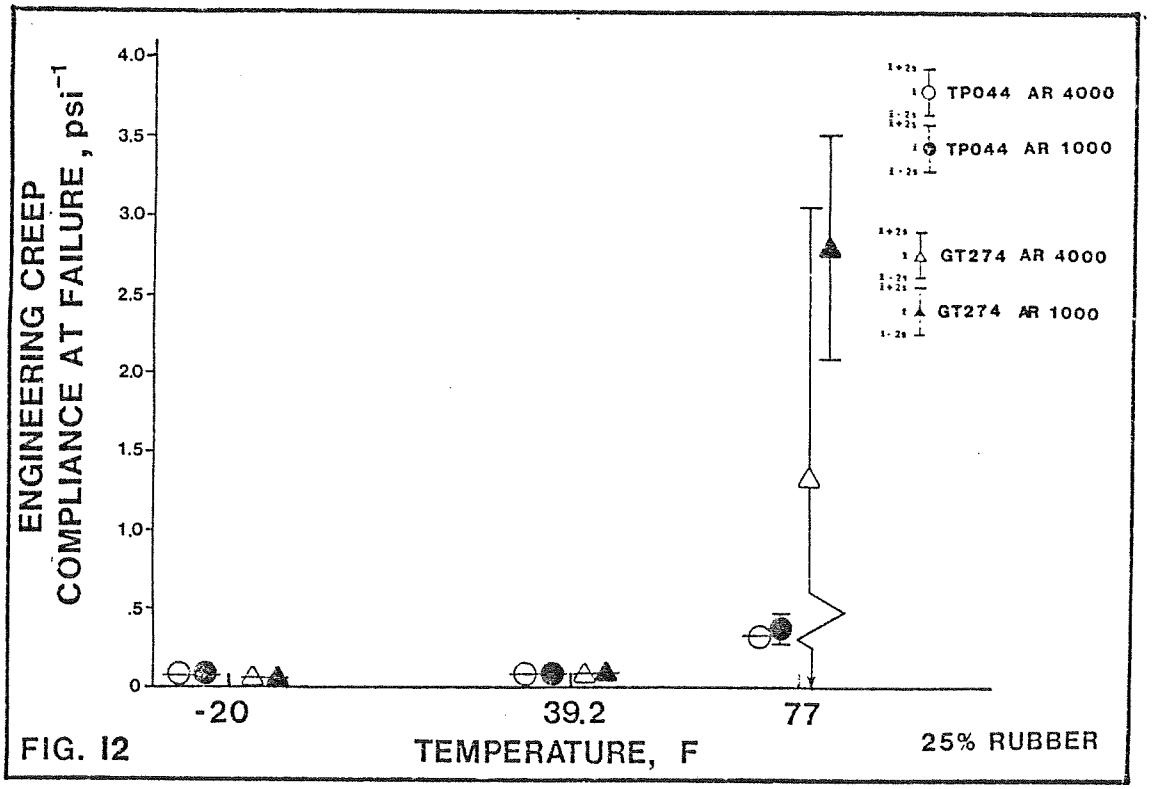
ENGINEERING CREEP COMPLIANCE AT FAILURE, psi$^{-1}$
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. I2

# APPENDIX J

## FORCE-DUCTILITY TRUE CREEP COMPLIANCE AT FAILURE

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

a. Calculated Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .0949<br>.0795<br>.0954<br>.0906<br>.0802<br>.0788 | .0912<br>.0811<br>.0782<br>.0587<br>.0698<br>.0614 | .0022<br>.0024<br>.0028<br>.00241<br>.00255<br>.00261 | .00218<br>.00213<br>.00215<br>.00205<br>.00207<br>.00311 | .0006<br>.0007<br>.0015<br>.0008<br>.0008<br>.0006 | .0004<br>.0004<br>.0006<br>.0007<br>.0006<br>.0005 |
| | 25% | .0663<br>.0759<br>.0622<br>.0720<br>.0759<br>.0661 | .0726<br>.1222<br>.0708<br>.0616<br>.0626<br>.0611 | .00227<br>.00221<br>.00256<br>.0023<br>.0024<br>.0028 | .00227<br>.00223<br>.00215<br>.00215<br>.00208<br>.00222 | .0009<br>.0009<br>.0009<br>.0009<br>.0008<br>.0006 | .0006<br>.0005<br>.0005<br>.0006<br>.0004 |
| AR1000 | 20% | .1286<br>.1211<br>.1265<br>.1303<br>.122<br>.121 | .0708<br>.1113<br>.0767<br>.0473<br>.0714<br>.0862 | .00521<br>.00375<br>.00490<br>.00348<br>.00382<br>.00414 | .00325<br>.00351<br>.00336<br>.00387<br>.00372<br>.00325 | .0007<br>.0014<br>.0008<br>.0007<br>.0007<br>.0007 | .0004<br>.0004<br>.0004<br>.0007<br>.0005<br>.0005 |
| | 25% | .0741<br>.0840<br>.0661<br>.0810<br>.0810<br>.0884 | .0523<br>.0836<br>.0839<br>.0677<br>.0745<br>.0833 | .00315<br>.00284<br>.00241<br>.00330<br>.00330<br>.00381 | .00296<br>.00306<br>.00277<br>.00284<br>.00284<br>.00309 | .0007<br>.0008<br>.0006<br>.0006<br>.0006<br>.0007 | .0008<br>.0005 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .0866 | .0734 | .0025 | .0023 | .0008 | .0005 |
| | | s | .0079 | .0124 | .0002 | .0004 | .0003 | .0001 |
| | | cv | 9.16 | 16.93 | 8.26 | 17.91 | 40.64 | 22.71 |
| | 25% | $\bar{x}$ | .0698 | .0752 | .0024 | .0022 | .0008 | .0005 |
| | | s | .0057 | .0236 | .0002 | .00007 | .0001 | .0008 |
| | | cv | 8.19 | 31.36 | 9.14 | 3.17 | 14.53 | 16.09 |
| AR1000 | 20% | $\bar{x}$ | .1249 | .0773 | .0042 | .0035 | .0008 | .0005 |
| | | s | .0041 | .0210 | .0007 | .0003 | .0002 | .0001 |
| | | cv | 3.27 | 27.22 | 16.35 | 7.35 | 33.66 | 24.19 |
| | 25% | $\bar{x}$ | .0792 | .0742 | .0031 | .0029 | .0007 | .0007 |
| | | s | .0079 | .0126 | .0005 | .0001 | .0002 | .0003 |
| | | cv | 10.00 | 16.91 | 15.03 | 4.56 | 20.53 | 40.89 |

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

a. Reduced Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .0899 | .0835 | .0025 | .0022 | .0009 | .0005 |
| | | .0832 | .0633 | .0025 | .0024 | .0007 | .0006 |
| | 25% | .0681 | .0885 | .0024 | .0022 | .0009 | .0004 |
| | | .0713 | .0618 | .0025 | .0022 | .0008 | .0005 |
| AR1000 | 20% | .1254 | .0863 | .0046 | .0034 | .0010 | .0004 |
| | | .1244 | .0683 | .0038 | .0036 | .0007 | .0006 |
| | 25% | .0747 | .0733 | .0028 | .0029 | .0007 | .0008 |
| | | .0836 | .0752 | .0034 | .0029 | .0008 | .0005 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .0866 | .0734 | .0025 | .0023 | .0008 | .00055 |
| | | s | .0059 | .0179 | 0 | .0002 | .0002 | .00009 |
| | | cv | 6.9 | 24.4 | 0 | 7.7 | 22.2 | 16.1 |
| | 25% | $\bar{x}$ | .0697 | .0752 | .00245 | .0022 | .00085 | .00045 |
| | | s | .0028 | .0237 | .00009 | 0 | .00009 | .00009 |
| | | cv | 4.1 | 31.5 | 3.6 | 0 | 10.4 | 19.7 |
| AR1000 | 20% | $\bar{x}$ | .1249 | .0773 | .0042 | .0035 | .0009 | .0005 |
| | | s | .00089 | .0160 | .0007 | .0002 | .0003 | .0002 |
| | | cv | .7 | 20.6 | 16.9 | 5.1 | 31.3 | 35.4 |
| | 25% | $\bar{x}$ | .0792 | .0743 | .0031 | .0029 | .00075 | .0007 |
| | | s | .0079 | .0017 | .0005 | 0 | .00009 | .0003 |
| | | cv | 10.0 | 2.3 | 17.2 | 0 | 11.8 | 40.9 |

Table J-3 -Log True Creep Compliance at Failure, $psi^{-1}$

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 1.0462 | 1.0783 | 2.6021 | 2.6576 | 3.0458 | 3.3010 |
| | | 1.0799 | 1.1986 | 2.6021 | 2.6198 | 3.1549 | 3.2218 |
| | 25% | 1.1669 | 1.0531 | 2.6198 | 2.6576 | 3.0458 | 3.3979 |
| | | 1.1469 | 1.2090 | 2.6021 | 2.6576 | 3.0969 | 3.3010 |
| AR1000 | 20% | .9017 | 1.0640 | 2.3372 | 2.4685 | 3.0000 | 3.3979 |
| | | .9052 | 1.1656 | 2.4202 | 2.4437 | 3.1549 | 3.2218 |
| | 25% | 1.1267 | 1.1349 | 2.5528 | 2.5376 | 3.1549 | 3.0969 |
| | | 1.0778 | 1.1238 | 2.4685 | 2.5376 | 3.0969 | 3.3010 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 1.0631 | 1.1385 | 2.6021 | 2.5863 | 3.1004 | 3.2614 |
| | | s | .0299 | .1066 | 0 | .0594 | .0967 | .0702 |
| | | cv | 2.8 | 9.4 | 0 | 2.3 | 3.1 | 2.2 |
| | 25% | $\bar{x}$ | 1.1569 | 1.1311 | 2.6110 | 2.6576 | 3.0714 | 3.3495 |
| | | s | .0177 | .1381 | .0157 | 0 | .0453 | .0859 |
| | | cv | 1.5 | 12.2 | 16.0 | 0 | 1.5 | 2.6 |
| AR1000 | 20% | $\bar{x}$ | .9035 | 1.1148 | 2.3787 | 2.4561 | 3.0775 | 3.3099 |
| | | s | .0031 | .0900 | .0735 | .0220 | .1372 | .1560 |
| | | cv | .3 | 8.1 | 3.1 | .9 | 4.5 | 4.7 |
| | 25% | $\bar{x}$ | 1.1023 | 1.1294 | 2.5107 | 2.5376 | 3.1259 | 3.1990 |
| | | s | .0433 | .0098 | .0747 | 0 | .0514 | .1808 |
| | | cv | 3.9 | .9 | 3.0 | 0 | 1.6 | 5.7 |

Table J-4 ANOVA Summary, -Log True Creep Compliance at Failure

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | .12535 | .12535 | 29.93 | 4.26 | 7.82 |
| Q | 1 | .02371 | .02371 | 5.66 | 4.26 | 7.82 |
| A | 1 | .07216 | .07216 | 17.23 | 4.26 | 7.82 |
| T | 2 | 36.86416 | 18.43208 | 4400.84 | 3.40 | 5.61 |
| RQ | 1 | .01107 | .01107 | 2.64 | 4.26 | 7.82 |
| RA | 1 | .00043 | .00043 | 0.10 | 4.26 | 7.82 |
| RT | 2 | .04475 | .02238 | 5.34 | 3.40 | 5.61 |
| QA | 1 | .00322 | .00322 | 0.77 | 4.26 | 7.82 |
| QT | 2 | .01344 | .00672 | 1.60 | 3.40 | 5.61 |
| AT | 2 | .04118 | .02059 | 4.92 | 3.40 | 5.61 |
| RQA | 1 | .01509 | .01509 | 3.60 | 4.26 | 7.82 |
| RAT | 2 | .01341 | .00671 | 1.60 | 3.40 | 5.61 |
| QAT | 2 | .01286 | .00643 | 1.54 | 3.40 | 5.61 |
| RQT | 2 | .01015 | .00508 | 0.21 | 3.40 | 5.61 |
| RQAT | 2 | .00737 | .00369 | 0.88 | 3.40 | 5.61 |
| Error | 24 | .10052 | .00419 | | | |
| TOTAL | 47 | 37.35887 | | | | |

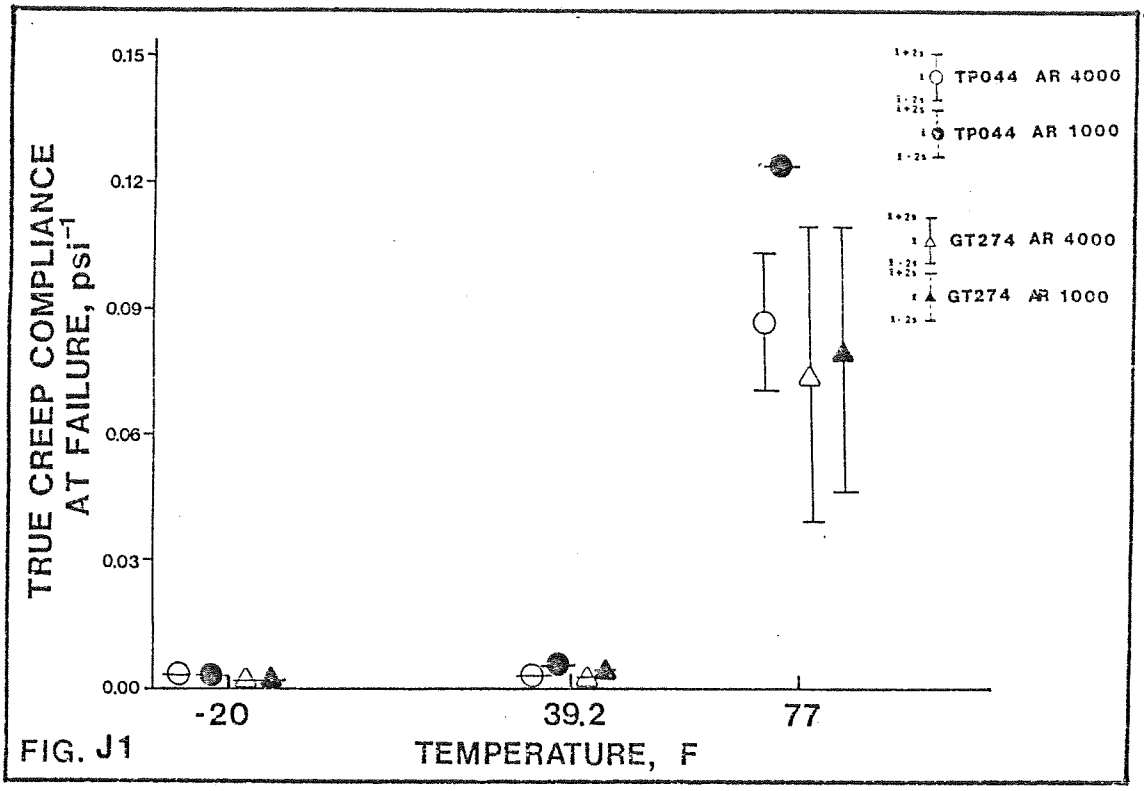


FIG. J1

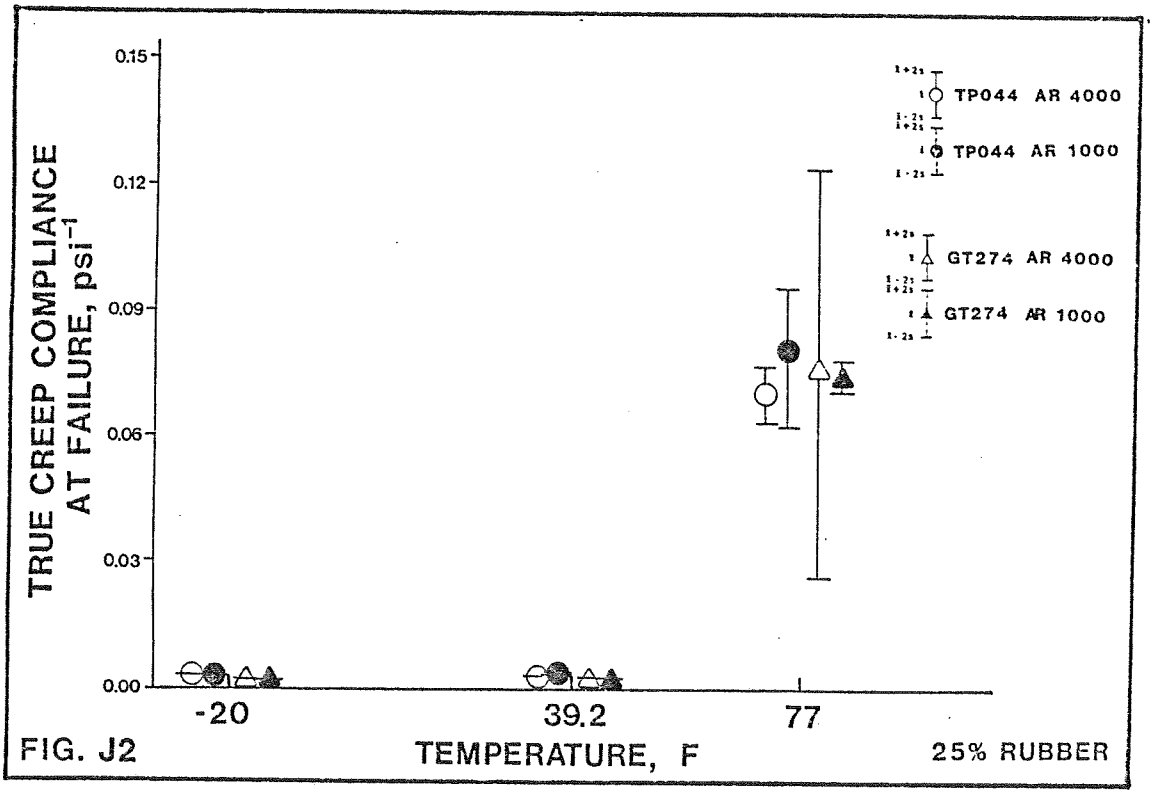


FIG. J2

25% RUBBER

# APPENDIX K

## FORCE-DUCTILITY MAXIMUM TRUE CREEP COMPLIANCE

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

a. Calculated Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .0949 | .1388 | .0033 | .0512 | .0006 | .0004 |
| | | .0818 | .1164 | .0034 | .00509 | .0007 | .0004 |
| | | .0954 | .1305 | .0037 | .0493 | .0015 | .0006 |
| | | .0921 | .0884 | .00343 | .00435 | .0008 | .0007 |
| | | .0882 | .0920 | .00338 | .00452 | .0008 | .0006 |
| | | .0883 | .1005 | .00346 | .00501 | .0006 | .0005 |
| | 25% | .0663 | .0883 | .00336 | .00694 | .0009 | .0006 |
| | | .0759 | .1274 | .00348 | .00659 | .0009 | .0005 |
| | | .0622 | .0761 | .00376 | .00649 | .0009 | |
| | | .0720 | .0849 | .0037 | .00688 | .0009 | .0005 |
| | | .0759 | .0883 | .0035 | .00657 | .0008 | .0006 |
| | | .0661 | .0883 | .0043 | .00680 | .0006 | .0004 |
| AR1000 | 20% | .1305 | .1294 | .00744 | .00931 | .0007 | .0004 |
| | | .1303 | .1656 | .00562 | .00981 | .0014 | .0004 |
| | | .1304 | .1304 | .00678 | .00939 | .0008 | .0004 |
| | | .1305 | .0768 | .00565 | .00990 | .0007 | .0007 |
| | | .123 | .1299 | .00583 | .00993 | .0007 | .0005 |
| | | .123 | .1305 | .00615 | .00924 | .0007 | .0005 |
| | 25% | .0741 | .1005 | .00621 | .00938 | .0007 | .0008 |
| | | .0840 | .1165 | .00538 | .00977 | .0008 | |
| | | .0661 | .1305 | .00496 | .00838 | .0006 | |
| | | .0810 | .1106 | .00604 | .00948 | .0006 | .0005 |
| | | .0813 | .1165 | .00598 | .00875 | .0006 | |
| | | .0884 | .1304 | .00642 | .00968 | .0007 | |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | .09012 | .11110 | .0034 | .0048 | .00083 | .00053 |
| | | s | .00512 | .02080 | .00014 | .00033 | .00034 | .00012 |
| | | cv | 5.68 | 18.73 | 3.95 | 6.83 | 40.64 | 22.71 |
| | 25% | $\bar{x}$ | .06973 | .09222 | .0037 | .0067 | .00083 | .00052 |
| | | s | .00571 | .01787 | .00034 | .00019 | .00012 | .00008 |
| | | cv | 8.19 | 19.38 | 9.13 | 2.77 | 14.53 | 16.09 |
| AR1000 | 20% | $\bar{x}$ | .12795 | .12710 | .0062 | .0096 | .00083 | .00048 |
| | | s | .00383 | .02845 | .00073 | .00032 | .00028 | .00012 |
| | | cv | 3.00 | 22.39 | 11.64 | 3.30 | 33.66 | 24.19 |
| | 25% | $\bar{x}$ | .07915 | .11750 | .0058 | .0092 | .00067 | .00665 |
| | | s | .00791 | .01161 | .00055 | .00055 | .00008 | .00027 |
| | | cv | 10.00 | 9.88 | 9.45 | 5.99 | 12.25 | 40.89 |

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

a. Reduced Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | .0907 | .1286 | .00347 | .00505 | .0009 | .0005 |
| | | .0895 | .0936 | .00342 | .00465 | .0007 | .0006 |
| | 25% | .0681 | .0973 | .00353 | .00667 | .0009 | .0006 |
| | | .0713 | .0872 | .00383 | .00675 | .0008 | .0005 |
| AR1000 | 20% | .1304 | .1418 | .00661 | .00950 | .0010 | .0004 |
| | | .1256 | .1124 | .00588 | .00969 | .0007 | .0006 |
| | 25% | .0747 | .1158 | .00552 | .00918 | .0007 | .0008 |
| | | .0836 | .1192 | .00615 | .00930 | .0006 | .0005 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{X}$ | .09010 | .11110 | .00345 | .00485 | .00080 | .00055 |
| | | S | .00106 | .03101 | .00004 | .00035 | .00018 | .00009 |
| | | CV | 1.2 | 27.9 | 1.2 | 7.2 | 22.2 | 16.1 |
| | 25% | $\bar{X}$ | .06970 | .09225 | .00368 | .00671 | .00085 | .00055 |
| | | S | .00284 | .00895 | .00027 | .00007 | .00009 | .00009 |
| | | CV | 4.1 | 9.7 | 7.3 | 1.0 | 10.4 | 16.1 |
| AR1000 | 20% | $\bar{X}$ | .12800 | .12710 | .00625 | .00945 | .00085 | .00050 |
| | | S | .00425 | .02605 | .00065 | .00010 | .00027 | .00018 |
| | | CV | 3.3 | 20.5 | 10.4 | 1.1 | 31.3 | 35.4 |
| | 25% | $\bar{X}$ | .07915 | .11750 | .00584 | .00924 | .00065 | .00065 |
| | | S | .00789 | .00301 | .00056 | .00011 | .00009 | .00027 |
| | | CV | 10.0 | 2.6 | 9.6 | 1.2 | 13.6 | 40.9 |

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

a. Analyzed Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 1.0424 | 0.8908 | 2.4597 | 2.2967 | 3.0458 | 3.3010 |
| | | 1.0482 | 1.0284 | 2.4660 | 2.3325 | 3.1549 | 3.2218 |
| | 25% | 1.1669 | 1.0119 | 2.4522 | 2.1759 | 3.0458 | 3.2218 |
| | | 1.1469 | 1.0595 | 2.4168 | 2.1707 | 3.0969 | 3.3010 |
| AR1000 | 20% | .8847 | .8483 | 2.1798 | 2.0223 | 3.0000 | 3.3979 |
| | | .9010 | .9492 | 2.2306 | 2.0137 | 3.1549 | 3.2218 |
| | 25% | 1.1267 | .9363 | 2.2581 | 2.0372 | 3.1549 | 3.0969 |
| | | 1.0778 | .9237 | 2.2111 | 2.0315 | 3.2218 | 3.3010 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 1.0453 | .9596 | 2.4629 | 2.3146 | 3.1004 | 3.2614 |
| | | s | .0051 | .1219 | .0056 | .0317 | .0967 | .0702 |
| | | cv | .5 | 12.7 | .2 | 1.4 | 3.1 | 2.2 |
| | 25% | $\bar{x}$ | 1.1569 | 1.0357 | 2.4345 | 2.1733 | 3.0714 | 3.2614 |
| | | s | .0177 | .0422 | .0314 | .0046 | .0453 | .0702 |
| | | cv | 1.5 | 4.1 | 1.3 | .2 | 1.5 | 2.2 |
| AR1000 | 20% | $\bar{x}$ | .8929 | .8988 | 2.2052 | 2.0180 | 3.0775 | 3.3099 |
| | | s | .0144 | .0894 | .0450 | .0076 | .1372 | .1560 |
| | | cv | 1.6 | 10.0 | 2.0 | .4 | 4.5 | 4.7 |
| | 25% | $\bar{x}$ | 1.1023 | .9300 | 2.2346 | 2.0344 | 3.1884 | 3.1990 |
| | | s | .0433 | .0112 | .0416 | .0051 | .0593 | .1808 |
| | | cv | 3.9 | 1.2 | 1.9 | .3 | 1.9 | 5.7 |

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

ANOVA

| SOURCE | df | SS | MS | F | F.05 | F.01 |
|---|---|---|---|---|---|---|
| R | 1 | 0.0276 | 0.0276 | 7.80 | 4.26 | 7.82 |
| Q | 1 | 0.0063 | 0.0063 | 1.78 | 4.26 | 7.82 |
| A | 1 | 0.1173 | 0.1173 | 33.08 | 4.26 | 7.82 |
| T | 2 | 38.2695 | 19.1350 | 5394.19 | 3.40 | 5.61 |
| RQ | 1 | 0.0236 | 0.0236 | 6.66 | 4.26 | 7.82 |
| RA | 1 | 0.0001 | 0.0001 | 0.05 | 4.26 | 7.92 |
| RT | 2 | 0.2540 | 0.1270 | 35.81 | 3.40 | 5.61 |
| QA | 1 | 0.0073 | 0.0073 | 2.08 | 4.26 | 7.82 |
| QT | 2 | 0.0436 | 0.0220 | 6.15 | 3.40 | 5.61 |
| AT | 2 | 0.1186 | 0.0590 | 16.72 | 3.40 | 5.61 |
| RQA | 1 | 0.0071 | 0.0071 | 2.03 | 4.26 | 7.82 |
| RAT | 2 | 0.0032 | 0.0010 | 0.46 | 3.40 | 5.61 |
| QAT | 2 | 0.0051 | 0.0020 | 0.72 | 3.40 | 5.61 |
| RQT | 2 | 0.0010 | 0.0005 | 0.15 | 3.40 | 5.61 |
| RQAT | 2 | 0.0161 | 0.0080 | 2.28 | 3.40 | 5.61 |
| Error | 24 | 0.0851 | 0.0035 | | | |
| TOTAL | 47 | 38.9862 | | | | |

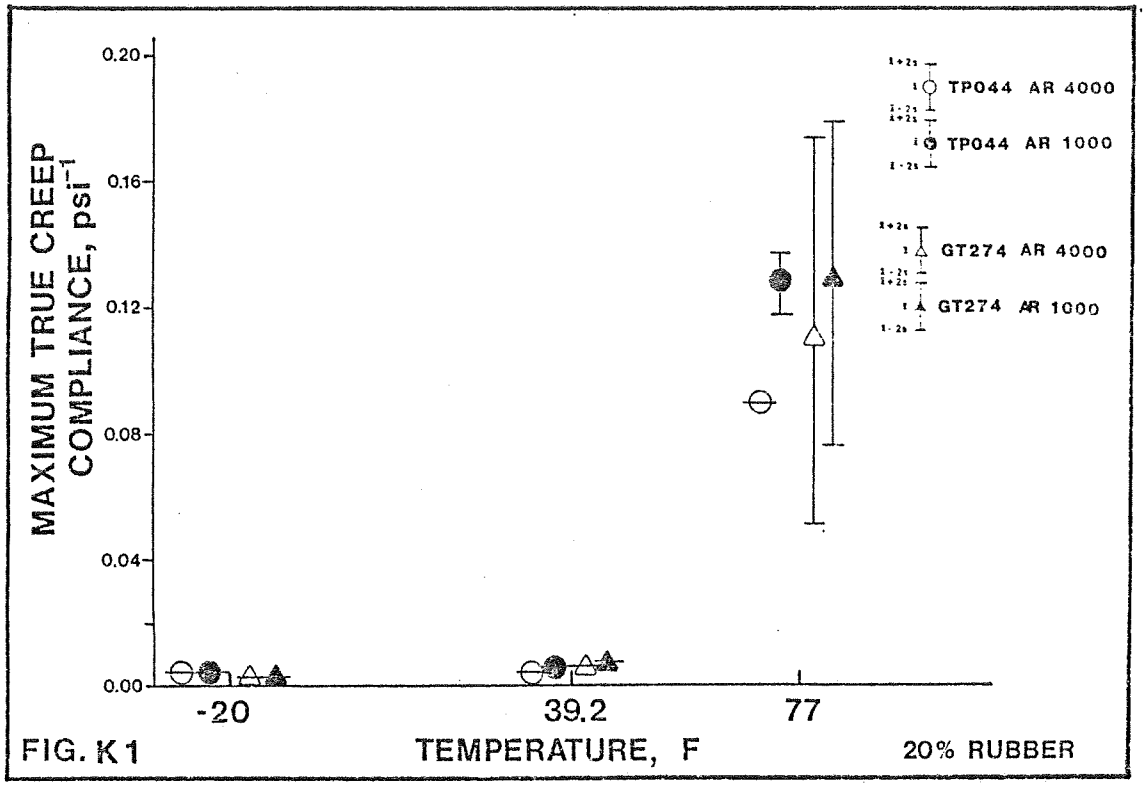
MAXIMUM TRUE CREEP COMPLIANCE, psi$^{-1}$
0.20
0.16
0.12
0.08
0.04
0.00
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. K1

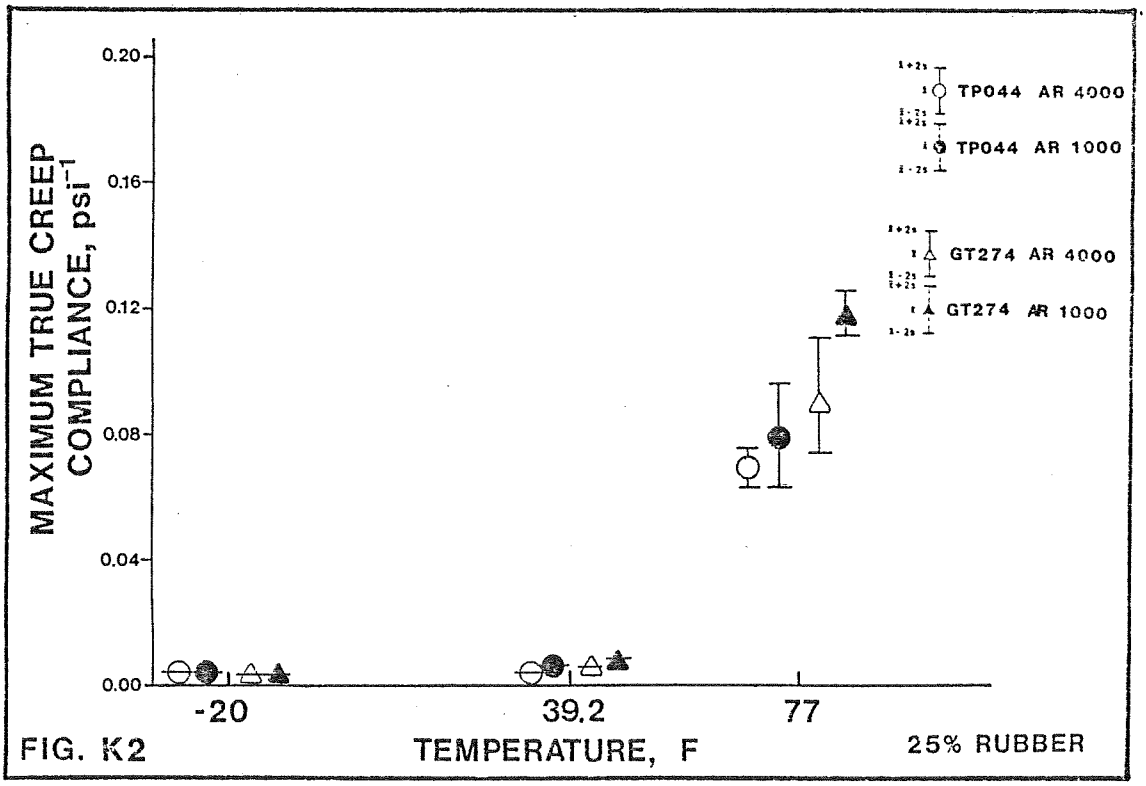
MAXIMUM TRUE CREEP COMPLIANCE, psi$^{-1}$
0.20
0.16
0.12
0.08
0.04
0.00
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. K2

# APPENDIX L

## FORCE DUCTILITY TIME TO MAXIMUM TRUE CREEP COMPLIANCE

Table L-1 Time to Maximum True Creep Compliance, minutes

a. Measured Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 14<br>14<br>14<br>14<br>12<br>13 | 12<br>13<br>12<br>14<br>12<br>12 | 10<br>10<br>11<br>11<br>11<br>11 | 12<br>13<br>13<br>13<br>13<br>13 | 1<br>1<br>1<br>1<br>1<br>1 | 1<br>1<br>1<br>1<br>1<br>1 |
| | 25% | 14<br>13<br>8<br>10<br>13<br>10 | 13<br>12<br>14<br>12<br>11<br>14 | 9<br>9<br>9<br>9<br>9<br>10 | 11<br>11<br>11<br>11<br>11<br>11 | 1<br>1<br>1<br>1<br>1<br>1 | 1<br>1<br><br>1<br>1<br>1 |
| AR1000 | 20% | 12<br>10<br>10<br>12<br>11<br>13 | 10<br>16<br>11<br>4<br>8<br>12 | 9<br>9<br>9<br>9<br>10<br>9 | 12<br>12<br>12<br>11<br>12<br>11 | 1<br>1<br>1<br>1<br>1<br>1 | 1<br>1<br>1<br>1<br>1<br>1 |
| | 25% | 16<br>10<br>14<br>10<br>10<br>12 | 14<br>13<br>13<br>13<br>13<br>13 | 7<br>8<br>7<br>7<br>7<br>7 | 10<br>9<br>9<br>10<br>11<br>10 | 1<br>1<br>1<br>1<br>1 | 1<br><br><br>1 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{X}$ | 13.5 | 12.5 | 10.67 | 12.83 | 1 | 1 |
| | | S | .84 | .84 | .52 | .41 | 0 | 0 |
| | | CV | 6.20 | 6.69 | 4.81 | 3.20 | 0 | 0 |
| | 25% | $\bar{X}$ | 11.3 | 12.7 | 9.17 | 11.00 | 1 | 1 |
| | | S | 2.34 | 1.21 | .41 | 0 | 0 | 0 |
| | | CV | 20.63 | 9.56 | 4.47 | 0 | 0 | 0 |
| AR1000 | 20% | $\bar{X}$ | 11.3 | 10.2 | 9.17 | 11.67 | 1 | 1 |
| | | S | 1.21 | 4.02 | .41 | .52 | 0 | 0 |
| | | CV | 10.69 | 39.55 | 4.47 | 4.46 | 0 | 0 |
| | 25% | $\bar{X}$ | 12.0 | 13.2 | 7.17 | 9.83 | 1 | 1 |
| | | S | 2.53 | .41 | .41 | .75 | 0 | 0 |
| | | CV | 21.08 | 3.10 | 5.72 | 7.63 | 0 | 0 |

Table L-2 Time to Maximum True Creep Compliance, minutes

a. Reduced Data

| | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|
| | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | 14.0 | 12.3 | 10.3 | 12.7 | 1 | 1 |
| | | 13.0 | 12.7 | 11.0 | 13.0 | 1 | 1 |
| | 25% | 11.7 | 13.0 | 9.0 | 11 | 1 | 1 |
| | | 11.0 | 12.3 | 9.3 | 11.0 | 1 | 1 |
| AR1000 | 20% | 10.7 | 12.3 | 9.0 | 12.0 | 1 | 1 |
| | | 12.0 | 8.0 | 9.3 | 11.3 | 1 | 1 |
| | 25% | 13.3 | 13.3 | 7.3 | 9.3 | 1 | 1 |
| | | 10.7 | 13.0 | 7.0 | 10.3 | 1 | 1 |

b. Summary

| | | | 77 F | | 39.2 F | | -20 F | |
|---|---|---|---|---|---|---|---|---|
| | | | TP044 | GT274 | TP044 | GT274 | TP044 | GT274 |
| AR4000 | 20% | $\bar{x}$ | 13.5 | 12.5 | 10.7 | 12.9 | 1 | 1 |
| | | s | .89 | .35 | .62 | .27 | 0 | 0 |
| | | cv | 6.6 | 2.8 | 5.8 | 2.1 | 0 | 0 |
| | 25% | $\bar{x}$ | 11.4 | 12.7 | 9.2 | 11.0 | 1 | 1 |
| | | s | .62 | .62 | .27 | 0 | 0 | 0 |
| | | cv | 5.5 | 4.9 | 2.9 | 0 | 0 | 0 |
| AR1000 | 20% | $\bar{x}$ | 11.4 | 10.2 | 9.2 | 11.7 | 1 | 1 |
| | | s | 1.15 | 3.81 | .27 | .62 | 0 | 0 |
| | | cv | 10.2 | 37.5 | 2.9 | 5.3 | 0 | 0 |
| | 25% | $\bar{x}$ | 12.0 | 13.2 | 7.2 | 9.8 | 1 | 1 |
| | | s | 2.30 | .27 | .27 | .89 | 0 | 0 |
| | | cv | 19.2 | 2.0 | 3.7 | 9.0 | 0 | 0 |

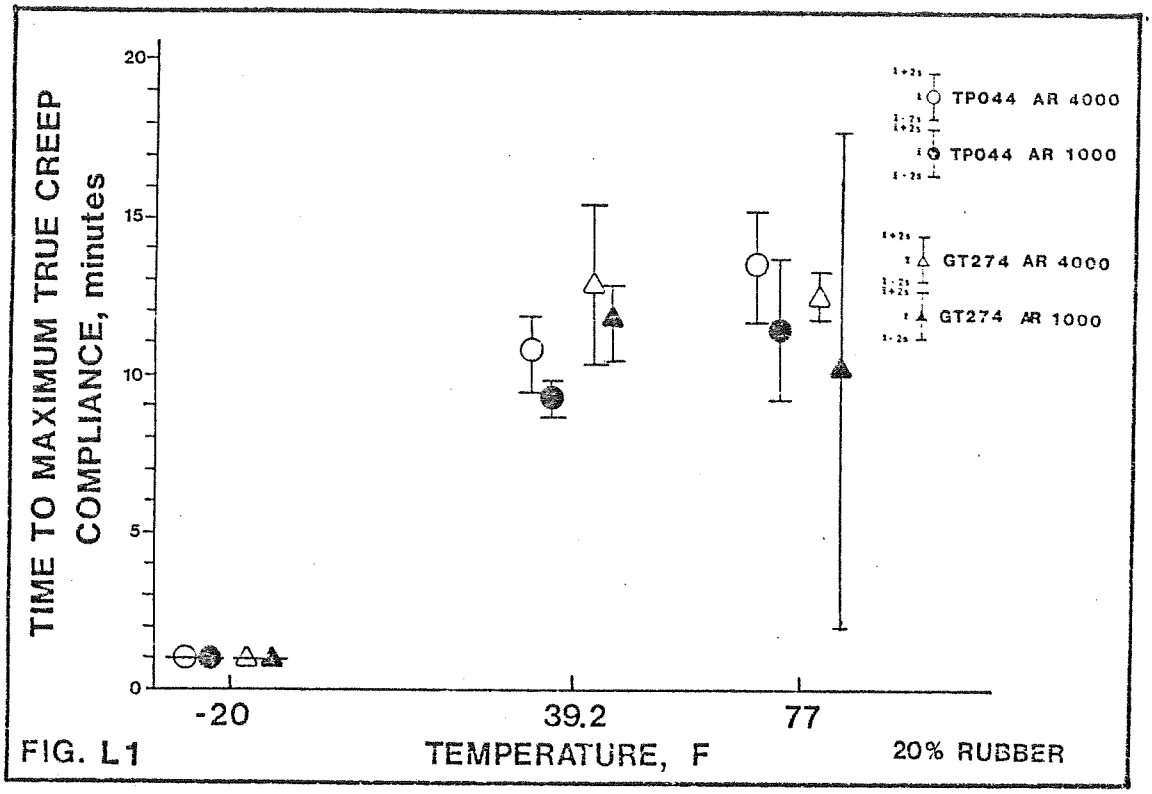
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, minutes
20
15
10
5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
20% RUBBER

FIG. L1

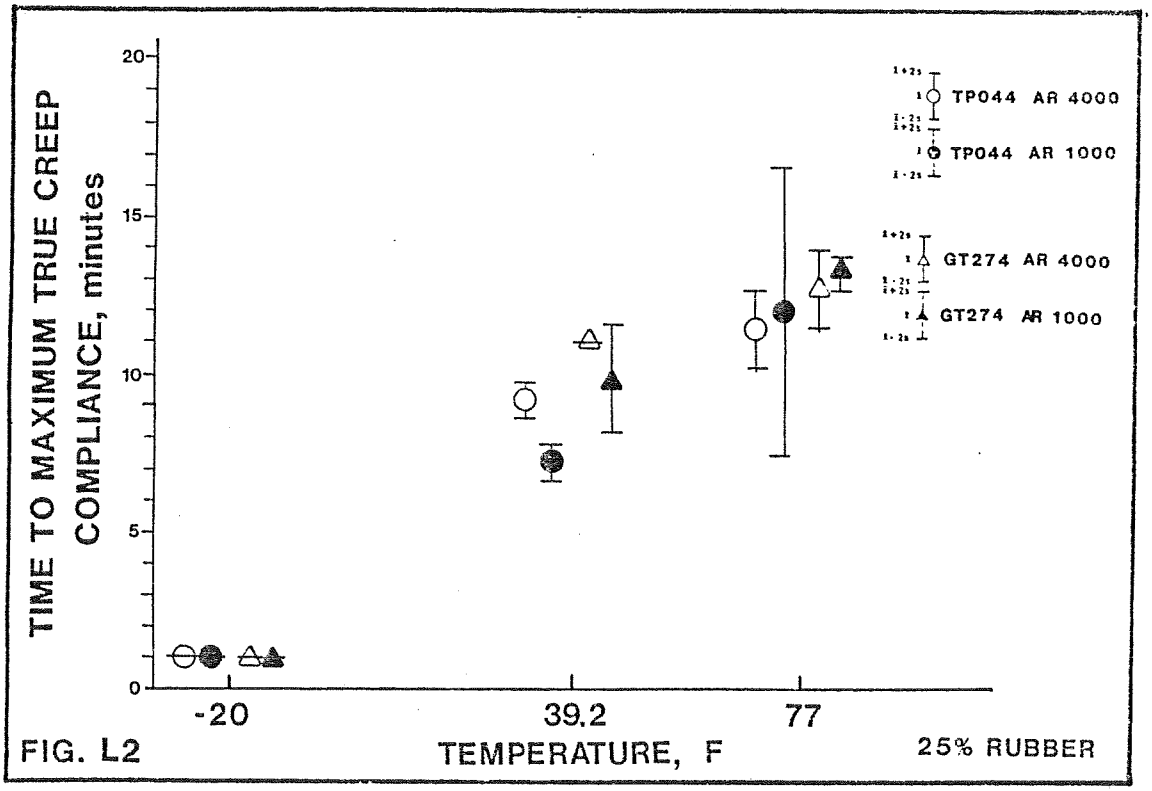
TIME TO MAXIMUM TRUE CREEP COMPLIANCE, minutes
20
15
10
5
0
-20
39.2
77
TEMPERATURE, F
TP044 AR 4000
TP044 AR 1000
GT274 AR 4000
GT274 AR 1000
25% RUBBER

FIG. L2