



TRI/ENVIRONMENTAL, INC.
A Texas Research International Company

**Creep and Creep-Rupture Behavior
of
Xgrid PET PVC 60/30 IT,
Xgrid PET PVC 120/30 IT, and
Xgrid PET PVC 200/30 IT**

PRELIMINARY REPORT

March, 2007

Submitted to:

TEMA Technologies and Materials
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Submitted by:

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A handwritten signature in black ink that reads 'C. Joel Sprague'. The signature is written in a cursive, flowing style.

C. Joel Sprague
Project Manager



March 16, 2007

Dr. Graziano Peterle

TEMA Technologies and Materials
Via dell'Industria, 21
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Subject: Creep Test Results for Xgrid PET PVC 60/ 30 IT, 120/ 30 IT, and 200/ 30 IT

Dear Dr. Peterle:

TRI/Environmental, Inc. (TRI) is pleased to present this preliminary report for creep testing of Xgrid soil reinforcement geogrid. The product was tested in the machine direction.

INTRODUCTION AND SUMMARY

Objective. The objective of this effort is to obtain an estimate of the creep-strain and creep rupture performance Xgrid PET PVC geogrids. Featured herein is accelerated creep testing using the stepped isothermal method (SIM) of time-temperature superposition (TTS) as well as conventional isothermal creep-rupture testing. The results apply to the machine direction.

Scope. Rapid loading tensile (RLT) and accelerated (SIM) and conventional creep tests were conducted. The purpose of RLT tests was to determine the ultimate tensile strength (UTS) of the product in order to establish the baseline for the creep tests. The conventional and accelerated creep testing results were used to derive a family rupture curve. The testing program is summarized in Table 1. Note that the conventional creep tests have not yet been completed.

Table 2. Test Matrix for R_FCR Project

(The number of single rib specimens to be tested under each condition is indicated)

Approx. % of UTL	Primary Product – PET PVC 120/30 IT		Secondary Products**	
	SIM	Conventional	PET PVC 60/ 30 IT - SIM	PET PVC 200/ 30 IT - SIM
85	1	1	1	1
80	1	1	1	1
75	1	1 single rib + 1 multi-rib*	1	1
70	1	1 single rib + 1 multi-rib*	1	1
65	1			
60	1			

* - Two multi-rib/wide-width specimens are included to validate the relevancy of single rib/strip data.

** - Secondary products made from the same yarn may be added to the program for product family characterization.



Summary. The creep rupture results are included in Table 2 and Figure 1.

Table 2. Summary of Creep-Rupture Results for the Xgrid Family

Reference Temperature of Rupture Regression Line	Regression Equation	Retained Strength (%)		Reduction Factor	
		75 Years	114 Years	75 Years	114 Years
20°C	%UTS = -2.734 hrs + 86.973	71.07	70.57	1.41	1.42
25°C	%UTS = -2.734 hrs + 85.743	69.84	69.34	1.43	1.44
30°C	%UTS = -2.734 hrs + 84.513	68.61	68.11	1.46	1.47
35°C	%UTS = -2.734 hrs + 83.283	67.38	66.88	1.48	1.50
40°C	%UTS = -2.734 hrs + 82.052	66.15	65.65	1.51	1.52

MATERIALS AND METHODS

Materials. The products described herein are a coated polyester (PET) geogrids.

Equipment

Testing platforms: Instron Model 4505 load frame under computer control (SIM);

TRI model DWCR dead weight & BTI multi-station lever action creep frames (conventional).

Environmental chamber: TRI Model SIW – stepped isothermal, wide chamber (SIM).

Grips: TRI Model PM-100, Pacman x 100mm (SIM);

TRI Model 3R-40, 3 roll x 36mm grips. (conventional)

Extensometer: Epsilon Model SW3542-0200-050-ST (SIM);

Trans Tek LVDT-dc, Model 0245-0000 (conventional)

Temperature controller: Watlow Series 982 programmable temperature controller (SIM).

Heating/cooling- Electrical/liquid CO₂ (SIM)

Data acquisition: HP-3852A data acquisition and control unit & Labview V5.1 software.

Procedures

SIM: Testing was conducted using single ribs of all geogrids. Each specimen was allowed to reach equilibrium at 20C prior to test initiation. Specimens were then ramped to the specified percentage of UTS and then held at that load until failure or 60k seconds. Temperature was stepped 14C every 10k seconds starting at 20C and ending at 90C. Strain was measured with an Epsilon extensometer with a 4.0-inch gauge length.

Conventional: Testing was conducted using single ribs of all geogrids. Each specimen was allowed to reach equilibrium at the prescribed temperatures prior to test initiation. Specimens were then ramped to the specified percentage of UTS and then held at that load until failure. Strain was measured with a TransTec LVDT with approximately a 6-inch gauge length.



RESULTS

RLT Results. RLT tests were run at a strain rate of 10%/minute to establish the baseline tensile strength of the specific product being tested.

Creep Rupture. A creep rupture curve for the Xgrid family of uniaxial geogrids derived from conventional and SIM testing is presented in Figure 1.

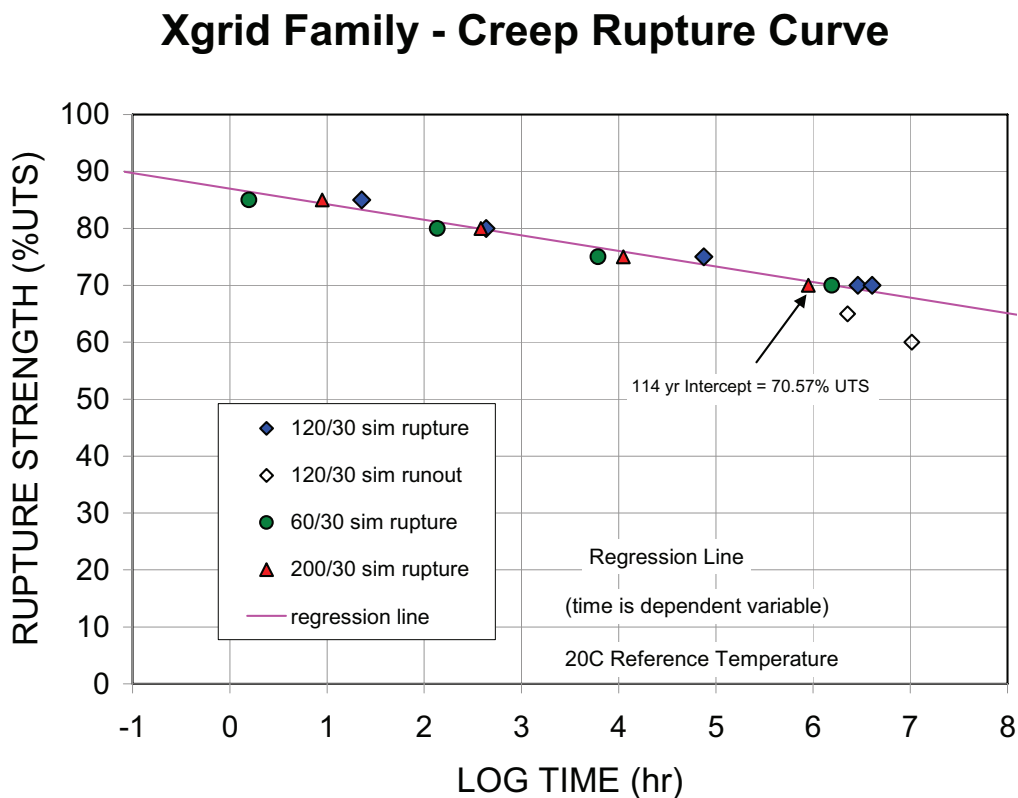
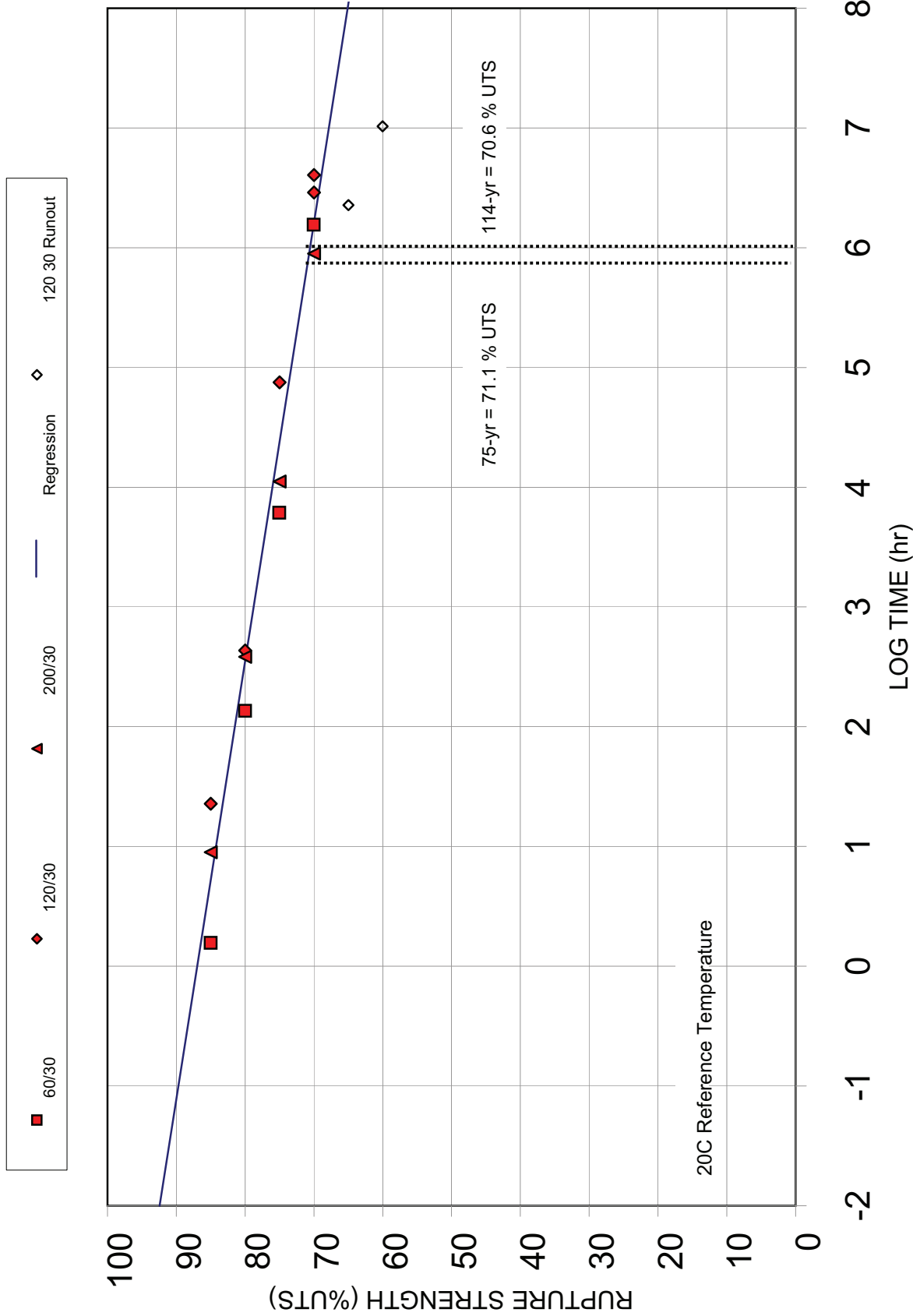


Figure 1. Creep Rupture Curve for the Xgrid Family

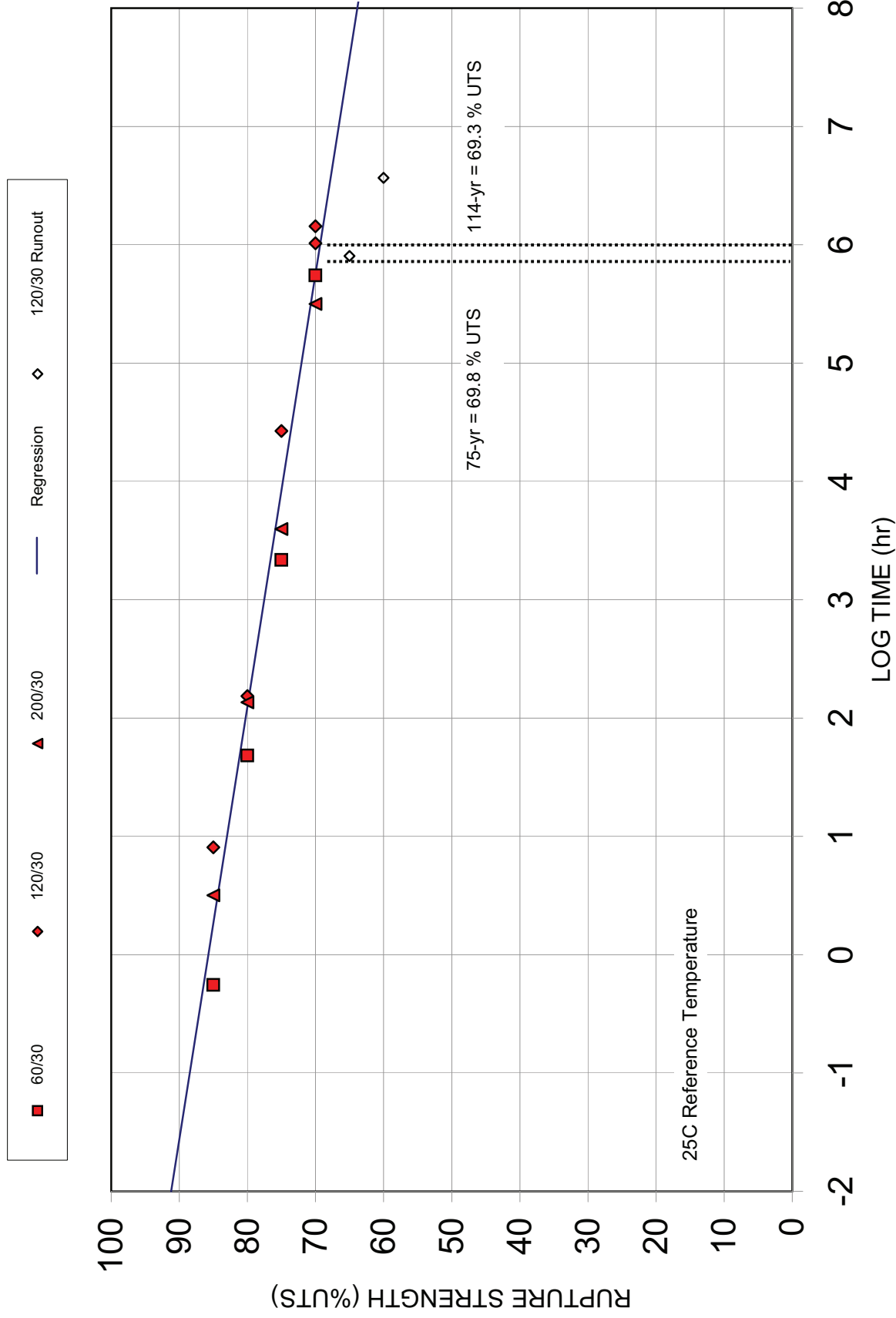
CONCLUSIONS AND RECOMMENDATIONS

Creep reduction factors have been determined for the family of products tested using conventional and accelerated (SIM) creep testing. These reduction factors are reasonably consistent with previously reported rupture-based reduction factors for this type of polyester (PET) geosynthetic. Additional longer-term testing is underway and will be added to this available data to further characterize the family of products.

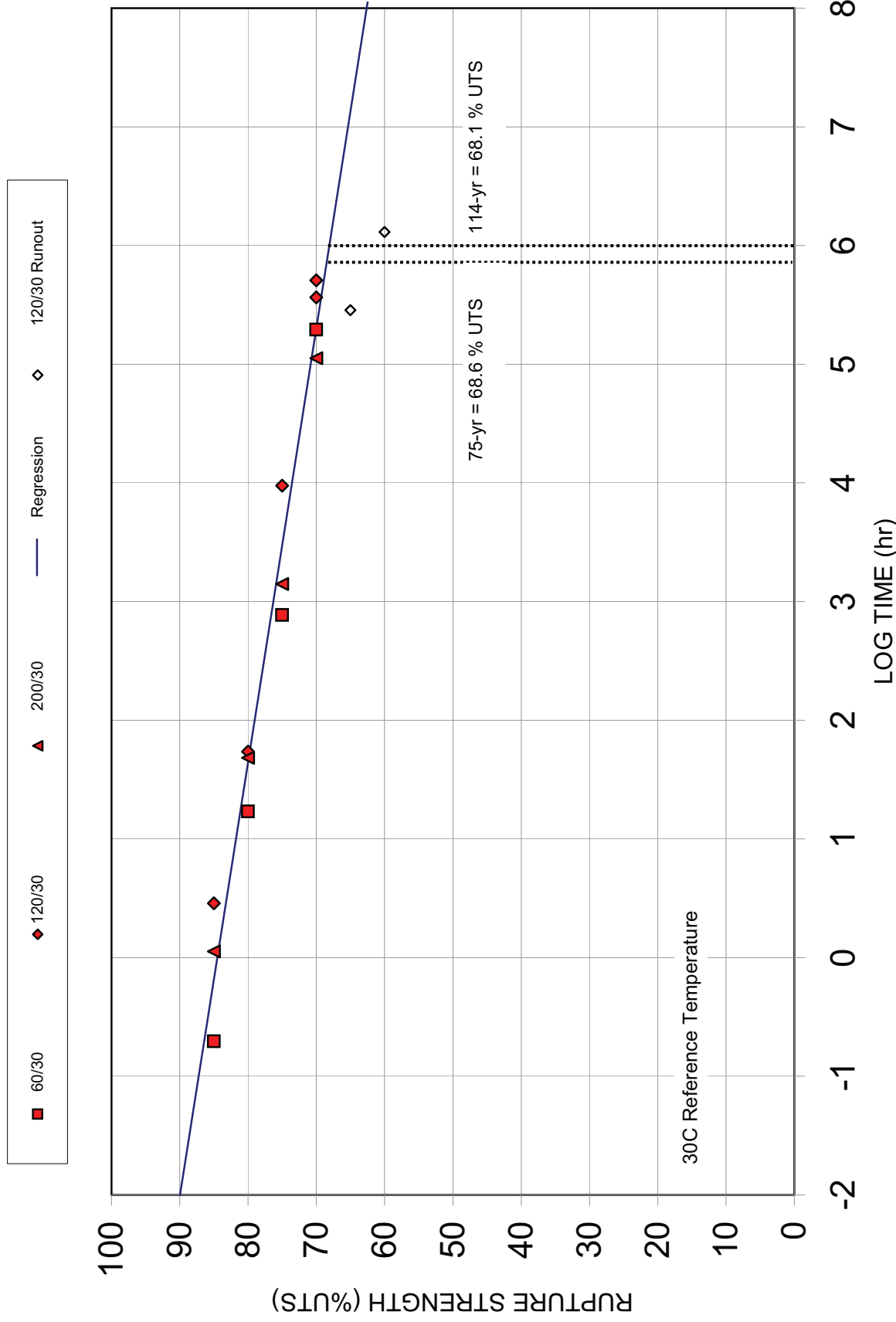
Xgrid - CREEP RUPTURE CURVE - 20C



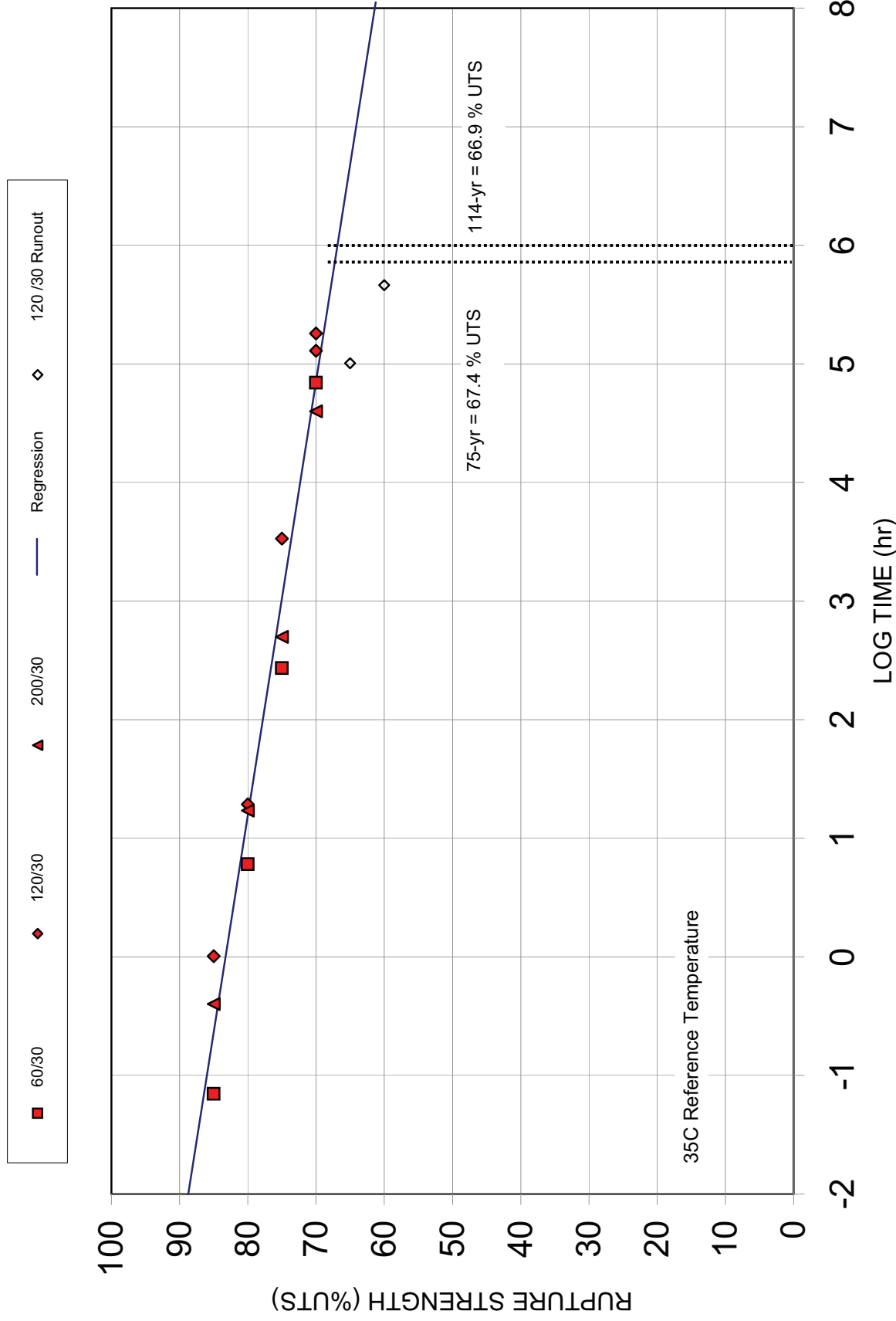
Xgrid - CREEP RUPTURE CURVE - 25C



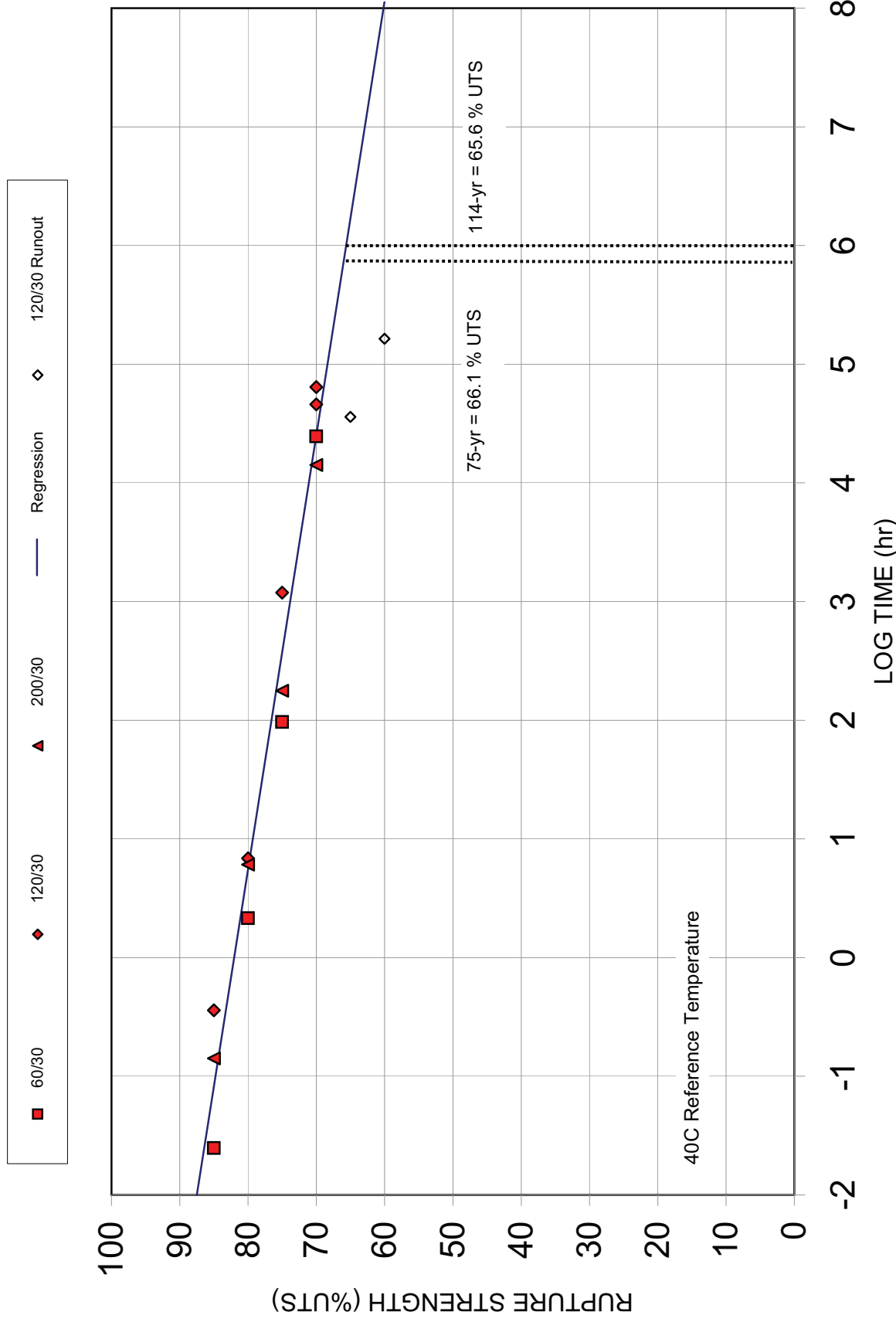
Xgrid - CREEP RUPTURE CURVE - 30C



Xgrid - CREEP RUPTURE CURVE - 35C



Xgrid - CREEP RUPTURE CURVE - 40C



SUMMARY CREEP PARAMETERS: TEMA

120/30

Specimen: 688t6u120sim60 Test Date: 08-Dec-06 Method: SIM (10⁴s, 14C), single rib, machine dir.

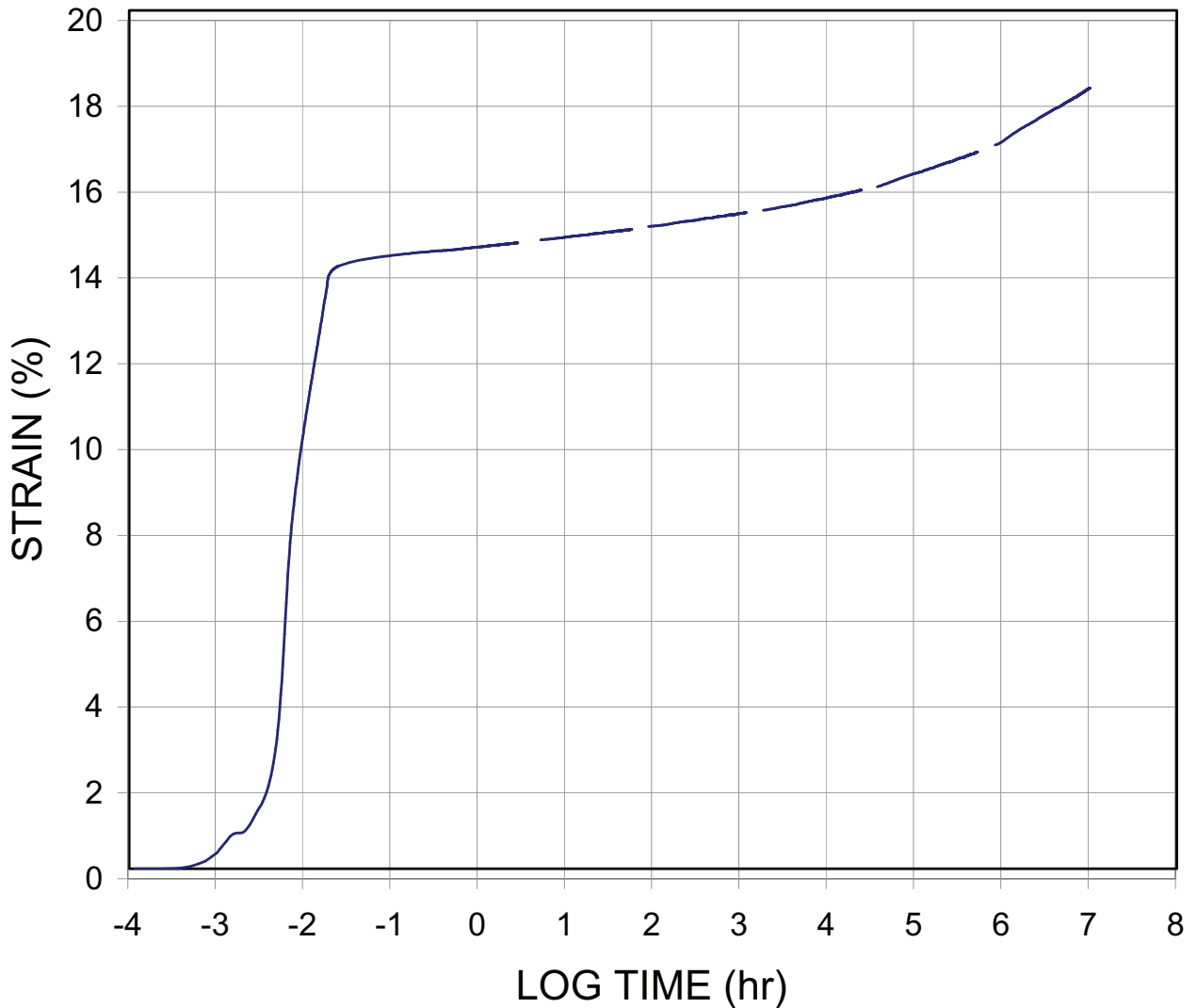
Average Creep Stress: 89.8 kN/m %UTS: 60.02

Ultimate Tensile Strength: 149.6 kN/m Rupture: NO

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.66	-
2	9500	10020	520	0.09	1.2834	33.62	0.0919
3	19500	20010	510	0.1	1.3127	47.46	0.0948
4	29500	30000	500	0.06	1.3209	61.38	0.0949
5	39500	39990	490	0.08	1.3292	75.31	0.0954
6	49500	49980	480	0.15	1.3378	88.92	0.0983

Summary	Initial	Final	Units	@20C refT
lab time	78.72	59940	sec	-
logA _T (t-t')	1.8961	7.0463	log hr	7.0147
A _T (t-t')	-	1269.25	years	1179.97
Strain	13.970	18.261	%	-
Modulus	642.9	491.8	kN/m	-

AVG 0.0951



SUMMARY CREEP PARAMETERS: TEMA

120/30

Specimen: 688t6u120sim65 Test Date: 29-Jan-07 Method: SIM (10⁴s, 14C), single rib, machine dir.

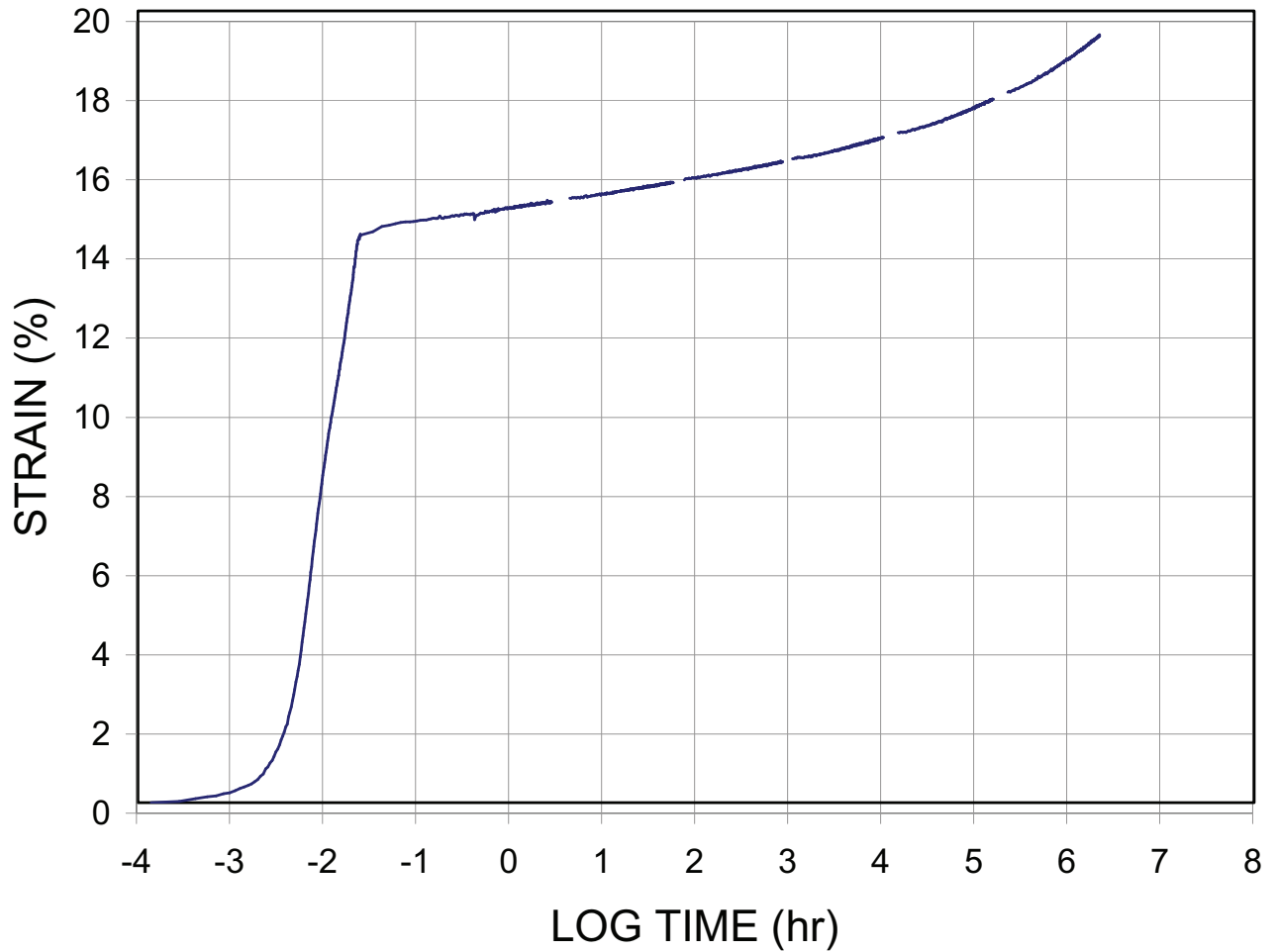
Average Creep Stress: 97.3 kN/m %UTS: 65.00

Ultimate Tensile Strength: 149.7 kN/m Rupture: NO

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.68	-
2	9500	10021	521	0.1	1.2826	33.13	0.0953
3	19300	20011	711	0.1	1.1684	46.81	0.0854
4	29100	30001	901	0.1	1.0734	60.60	0.0778
5	39300	39991	691	0.11	1.1963	74.23	0.0878
6	49300	49981	681	0.16	1.1941	87.91	0.0872

Summary	Initial	Final	Units	@20C refT
lab time	79	59941	sec	-
logA _T (t-t')	1.8976	9.9419	log hours	6.3553
A _T (t-t')	-	277.22	years	258.52
Strain	13.801	19.469	%	-
Modulus	670.1	499.7	kN/m	-

AVG 0.0867

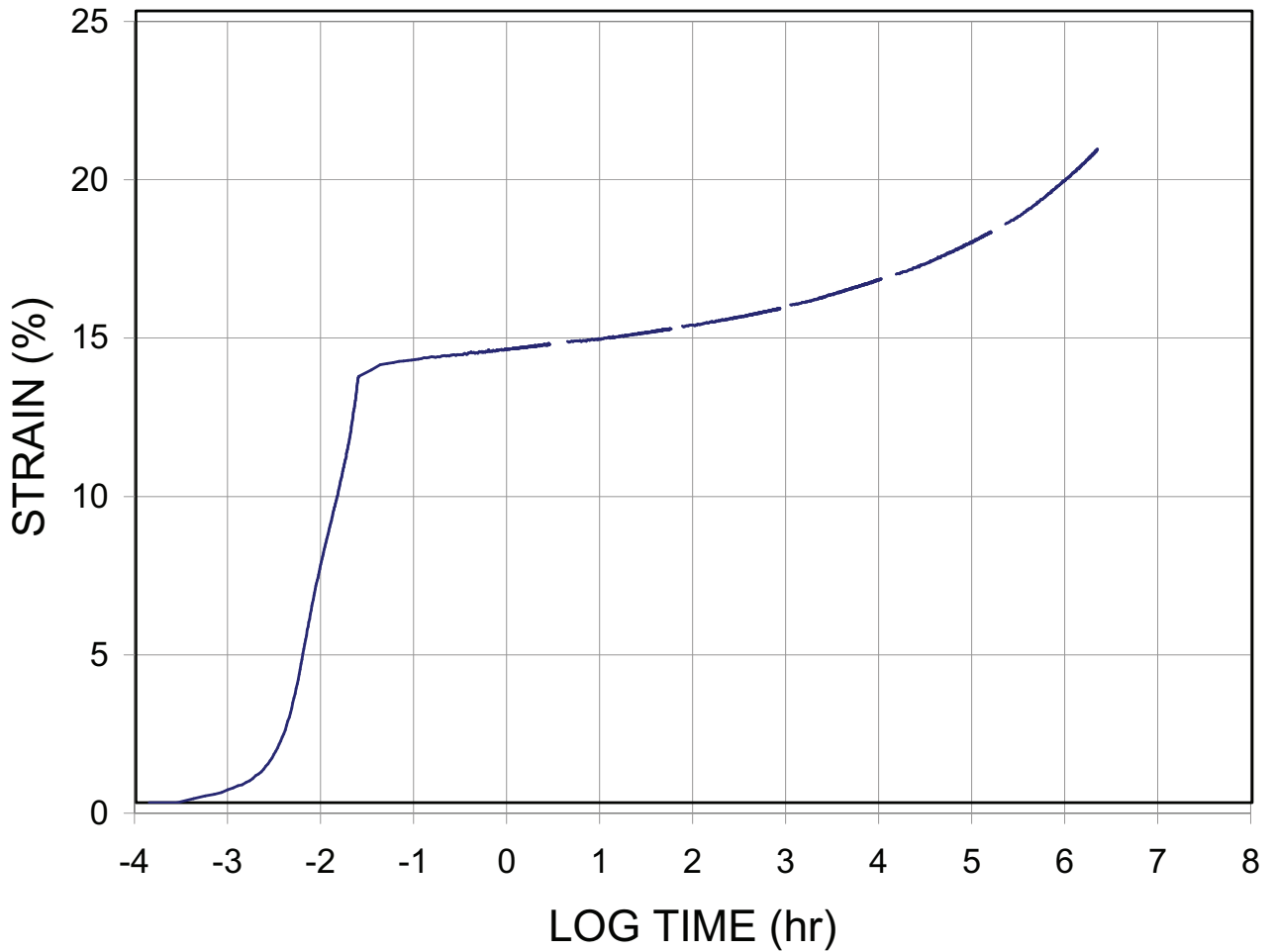


SUMMARY CREEP PARAMETERS: TEMA
120/30

Specimen: 688t6u120sim70 Test Date: 30-Jan-07 Method: SIM (10⁴s, 14C),single rib, machine dir.
 Average Creep Stress: 104.8 kN/m %UTS: 70.00
 Ultimate Tensile Strength: 149.7 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.79	-
2	9500	10022	522	0.1	1.2823	33.06	0.0966
3	19300	20012	712	0.1	1.1682	46.57	0.0864
4	29100	30002	902	0.1	1.0732	60.10	0.0793
5	39300	39992	692	0.11	1.1960	73.76	0.0876
6	49300	49982	682	0.16	1.1939	87.18	0.0889

Summary	Initial	Final	Units	@20C refT	AVG
lab time	79	62642	sec	-	
logA _T (t-t')	1.8976	10.0388	log hours	6.4618	
A _T (t-t')	-	346.52	years	330.36	
Strain	12.366	21.101	%	-	
Modulus	717.5	496.6	kN/m	-	



SUMMARY CREEP PARAMETERS: TEMA

120/30

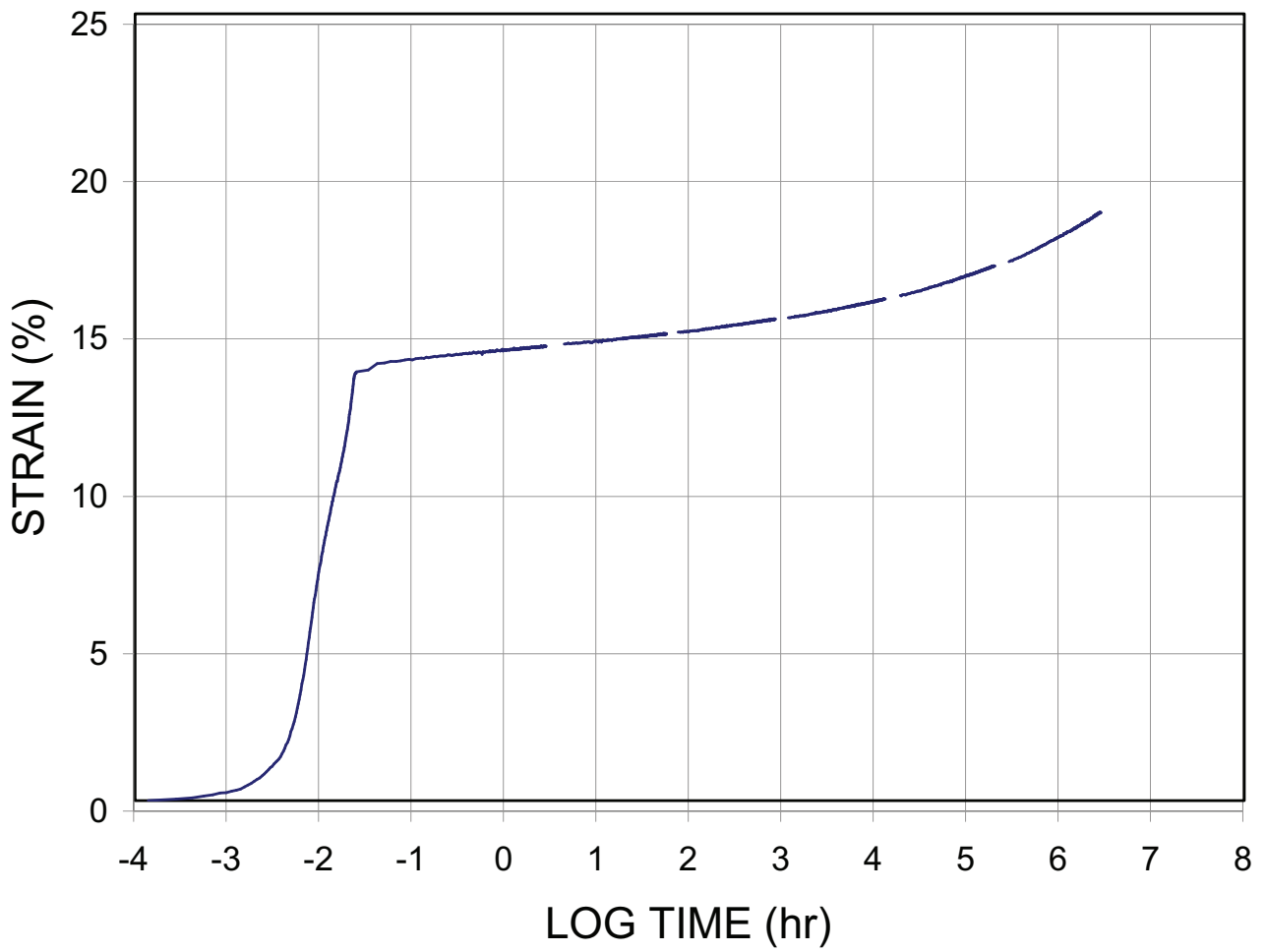
Specimen: 688t6u120sim70b Test Date: 01-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

Average Creep Stress: 104.8 kN/m %UTS: 70.00

Ultimate Tensile Strength: 149.7 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.57	-
2	9500	10020	520	0.1	1.2835	33.35	0.0931
3	19300	20010	710	0.08	1.1691	47.26	0.0841
4	29300	30000	700	0.06	1.1830	61.27	0.0844
5	39300	39990	690	0.09	1.1889	75.33	0.0846
6	49300	49980	680	0.08	1.1948	89.37	0.0851

Summary	Initial	Final	Units	@20C refT	AVG
lab time	79	64560	sec	-	0.0862
logA _T (t-t')	1.8976	10.2028	log hours	6.6062	
A _T (t-t')	-	505.42	years	460.66	
Strain	12.766	19.102	%	-	
Modulus	735.0	548.5	kN/m	-	



SUMMARY CREEP PARAMETERS: TEMA

120/30

Specimen: 688t6u120sim75b Test Date: 02-Feb-07 Method: SIM (10⁴s, 14C), single rib, machine dir.

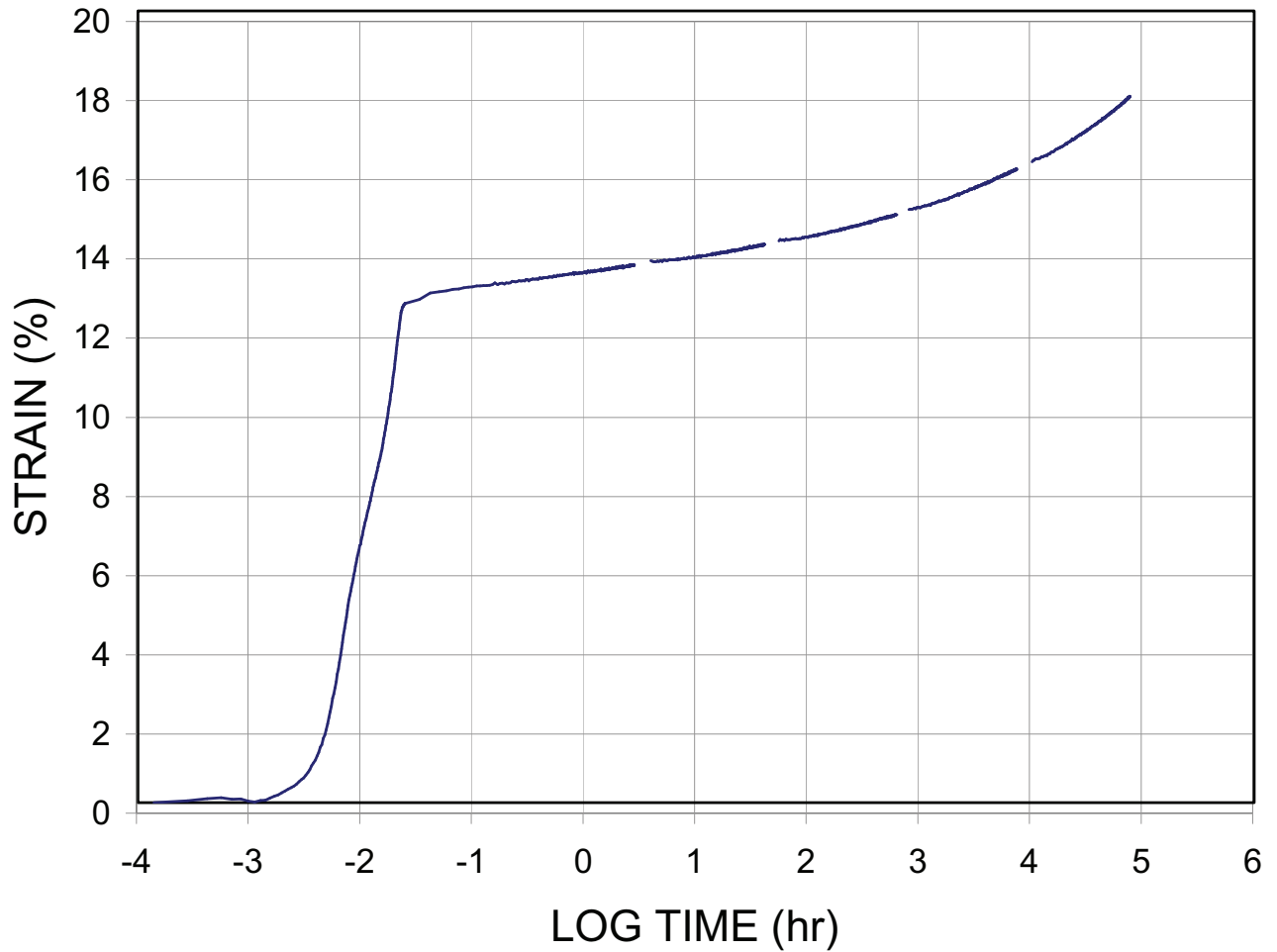
Average Creep Stress: 112.3 kN/m %UTS: 75.00

Ultimate Tensile Strength: 149.7 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.85	-
2	9300	10020	720	0.1	1.1424	32.36	0.0913
3	19300	20010	710	0.12	1.1774	45.42	0.0902
4	29100	30000	900	0.13	1.0740	58.75	0.0806
5	39100	39990	890	0.15	1.0865	72.20	0.0807
6							

Summary	Initial	Final	Units	@20C refT
lab time	79	48330	sec	-
logA _T (t-t')	1.8976	8.4455	log hours	4.8758
A _T (t-t')	-	8.84	years	8.57
Strain	11.982	17.846	%	-
Modulus	883.3	629.2	kN/m	-

AVG 0.0856



SUMMARY CREEP PARAMETERS: TEMA

120/30

Specimen: 688t6u120sim80 Test Date: 05-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

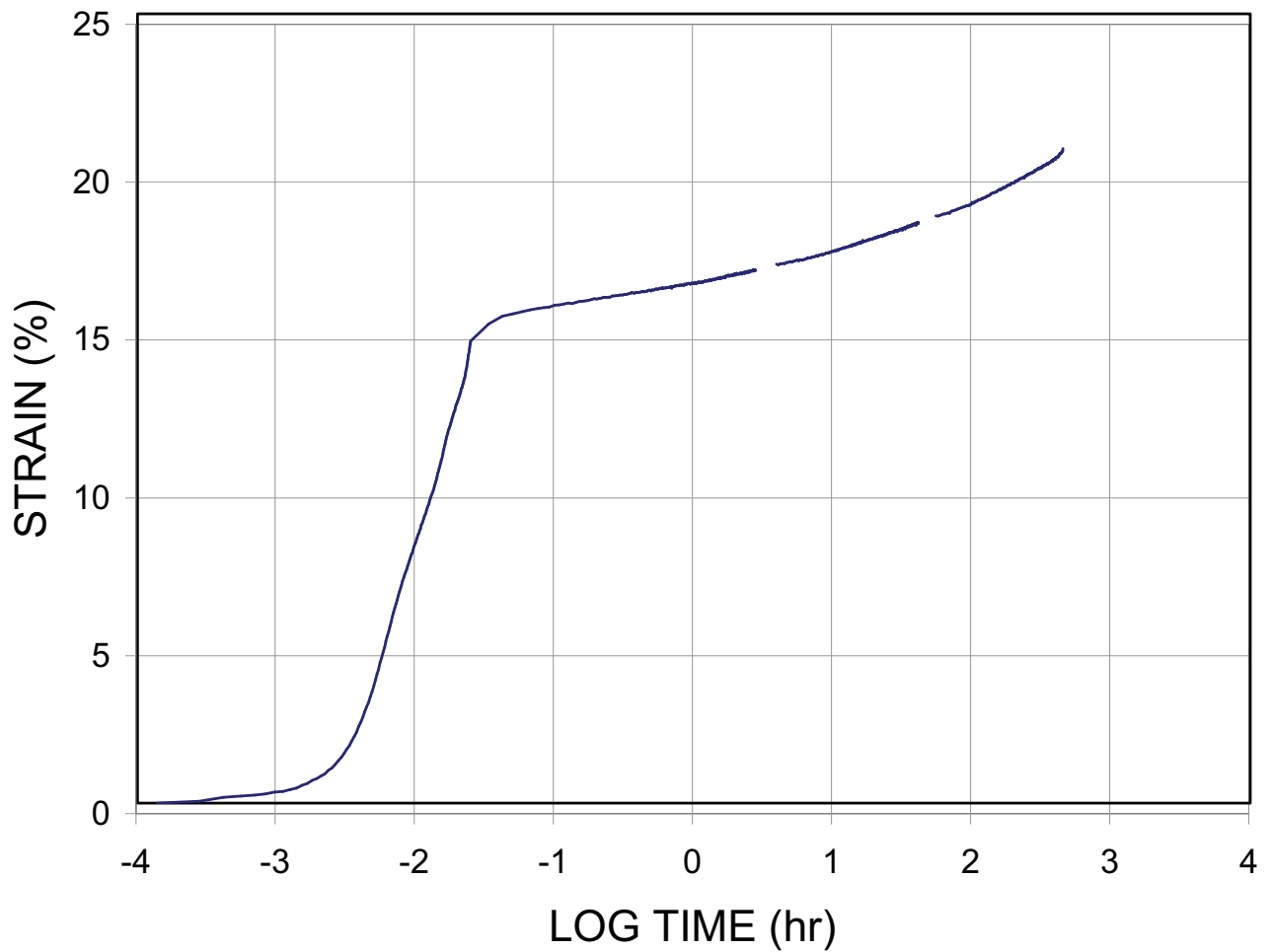
Average Creep Stress: 119.7 kN/m %UTS: 80.00

Ultimate Tensile Strength: 149.7 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.80	-
2	9300	10021	721	0.15	1.1418	32.85	0.0875
3	19300	20011	711	0.15	1.1769	46.24	0.0879
4							
5							
6							

Summary	Initial	Final	Units	@20C refT
lab time	79	27091	sec	-
logA _T (t-t')	1.8976	6.2102	log hours	2.6362
A _T (t-t')	-	0.05	years	0.05
Strain	13.288	20.736	%	-
Modulus	740.8	577.5	kN/m	-

AVG 0.0877



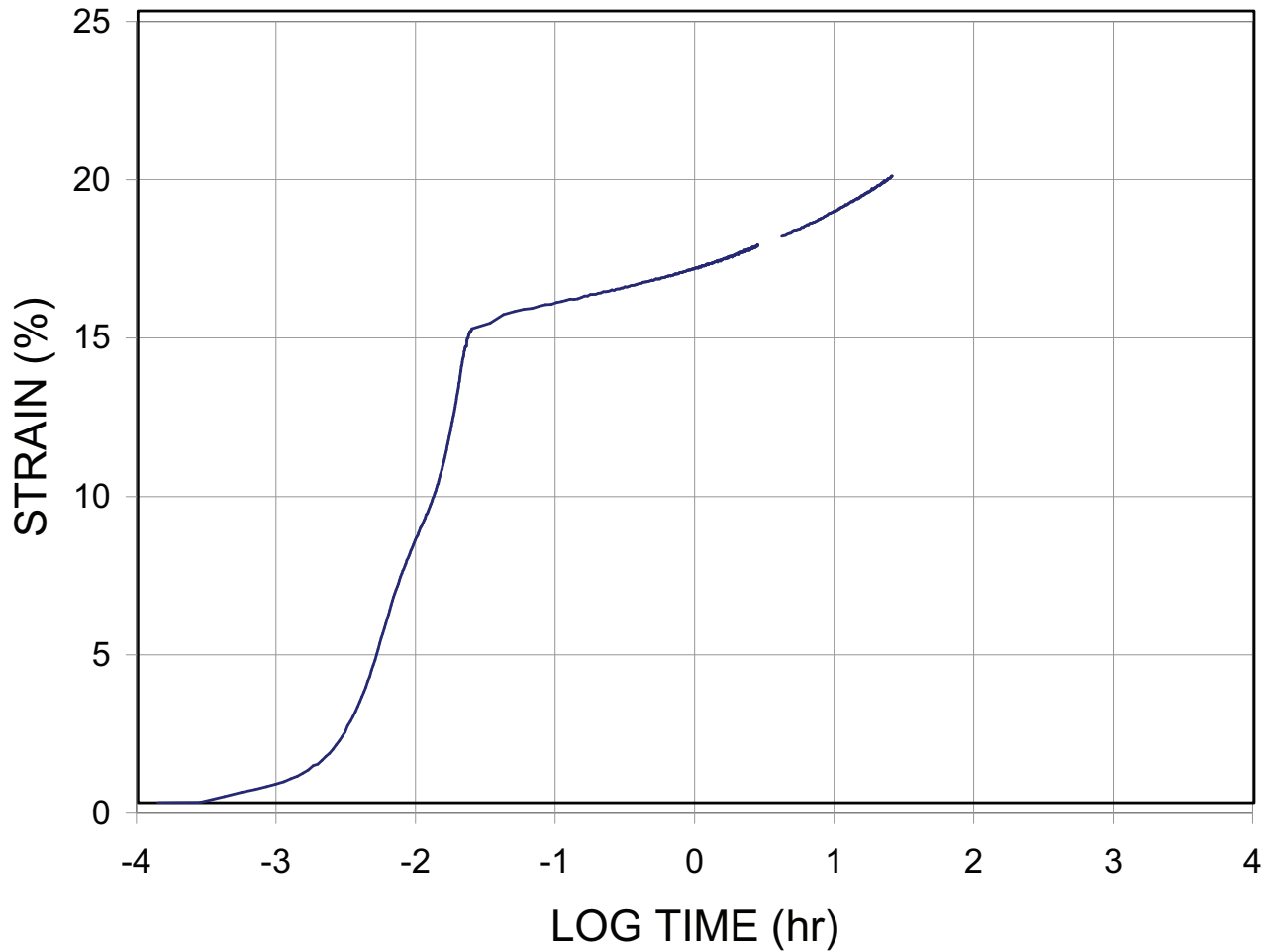
SUMMARY CREEP PARAMETERS: TEMA
120/30

Specimen: 688t6u120sim85 Test Date: 07-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.
 Average Creep Stress: 127.2 kN/m %UTS: 85.00
 Ultimate Tensile Strength: 149.7 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.41	-
2	9400	10020	620	0.08	1.2069	33.78	0.0840
3							
4							
5							
6							

Summary	Initial	Final	Units	@20C refT
lab time	79	15090	sec	-
logA _T (t-t')	1.8976	4.9621	log hours	1.3566
A _T (t-t')	-	0.00	years	0.00
Strain	14.291	19.792	%	-
Modulus	865.9	642.8	kN/m	-

AVG 0.0840



SUMMARY CREEP PARAMETERS: TEMA

200/30

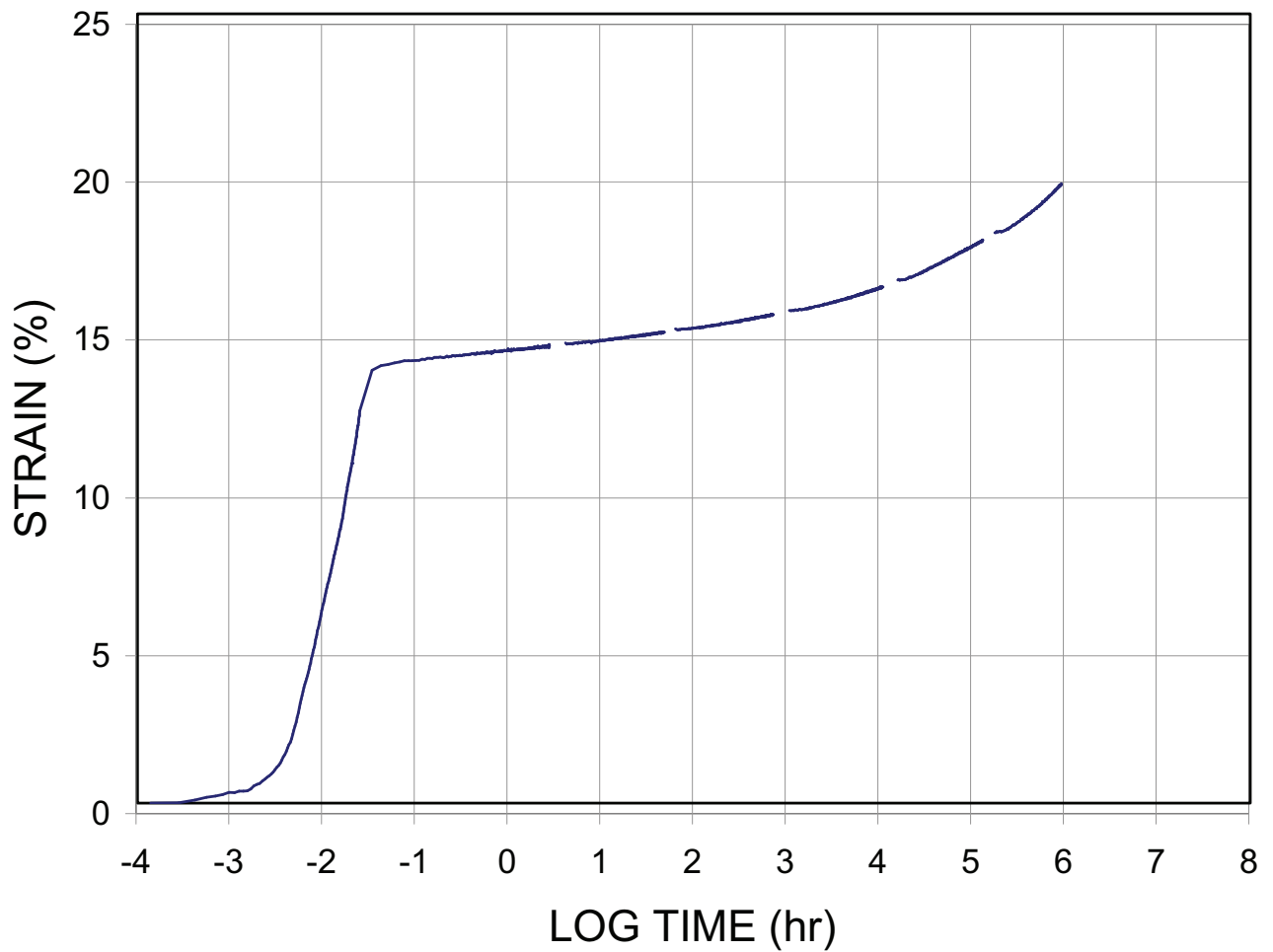
Specimen: 688t6u200sim70 Test Date: 06-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

Average Creep Stress: 170.4 kN/m %UTS: 70.00

Ultimate Tensile Strength: 243.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.85	-
2	9400	10022	622	0.1	1.2058	32.92	0.0922
3	19300	20012	712	0.1	1.1720	46.48	0.0864
4	29300	30002	702	0.16	1.1819	60.05	0.0871
5	39100	39992	892	0.4	1.0774	73.53	0.0799
6	49100	49982	882	0.2	1.0900	86.72	0.0827

Summary	Initial	Final	Units	@20C refT	AVG
lab time	79	55322	sec	-	0.0856
logA _T (t-t')	1.8976	9.5211	log hours	5.9508	
A _T (t-t')	-	105.18	years	101.86	
Strain	11.247	19.625	%	-	
Modulus	1014.2	868.1	kN/		



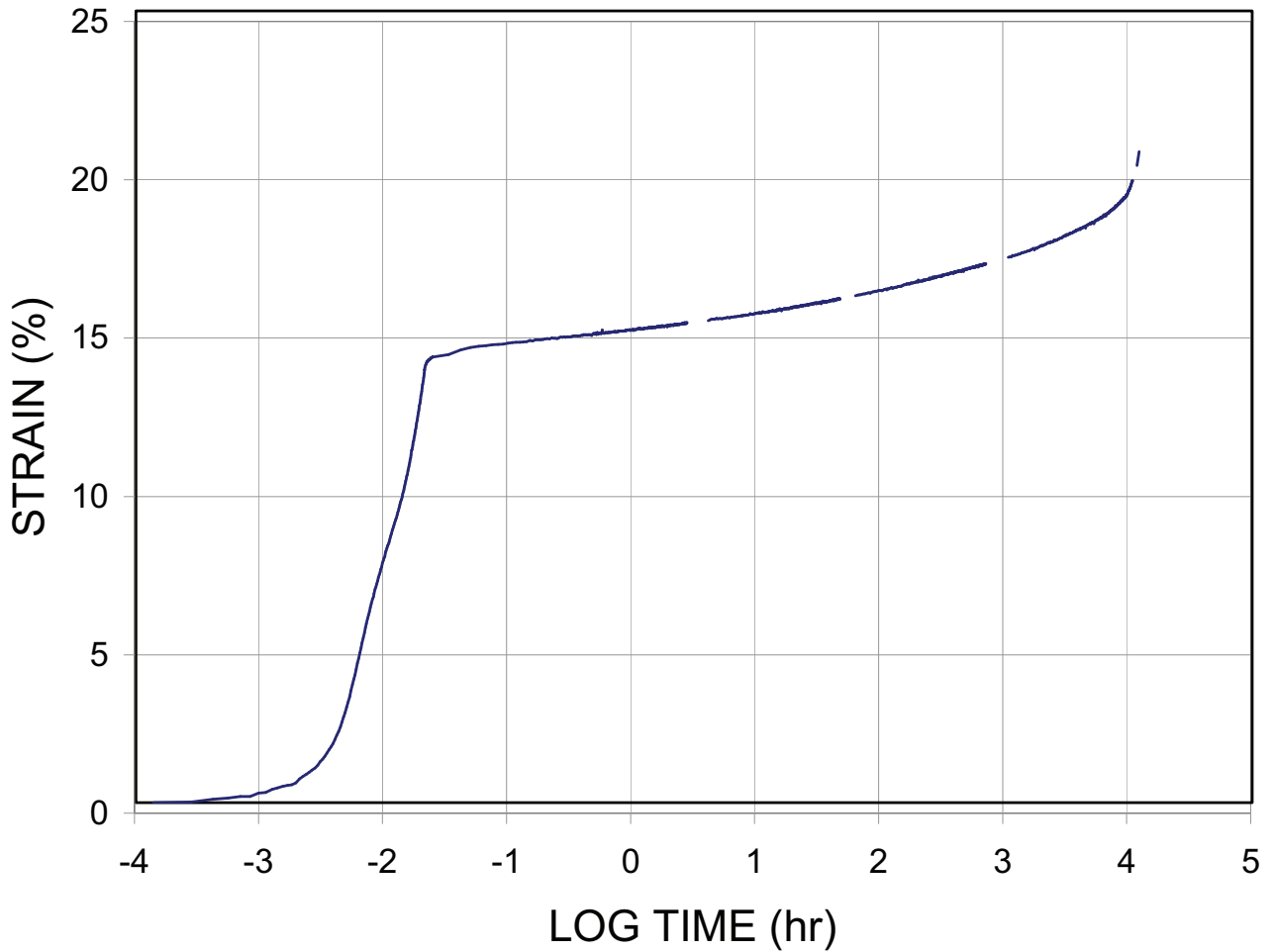
SUMMARY CREEP PARAMETERS: TEMA
200/30

Specimen: 688t6u200sim75 Test Date: 08-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.
 Average Creep Stress: 182.5 kN/m %UTS: 75.00
 Ultimate Tensile Strength: 243.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.54	-
2	9400	10020	620	0.1	1.2075	33.06	0.0894
3	19300	20010	710	0.1	1.1735	46.53	0.0871
4	29300	30000	700	0.1	1.1833	60.18	0.0867
5	39300	39990	690	0.4	1.1892	71.73	0.1029
6							

Summary	Initial	Final	Units	@20C refT
lab time	78.05	40080	sec	-
logA _T (t-t')	1.8924	7.6453	log hours	4.0482
A _T (t-t')	-	1.40	years	1.27
Strain	13.828	20.552	%	-
Modulus	1320.7	888.2	kN/m	-

AVG 0.0911

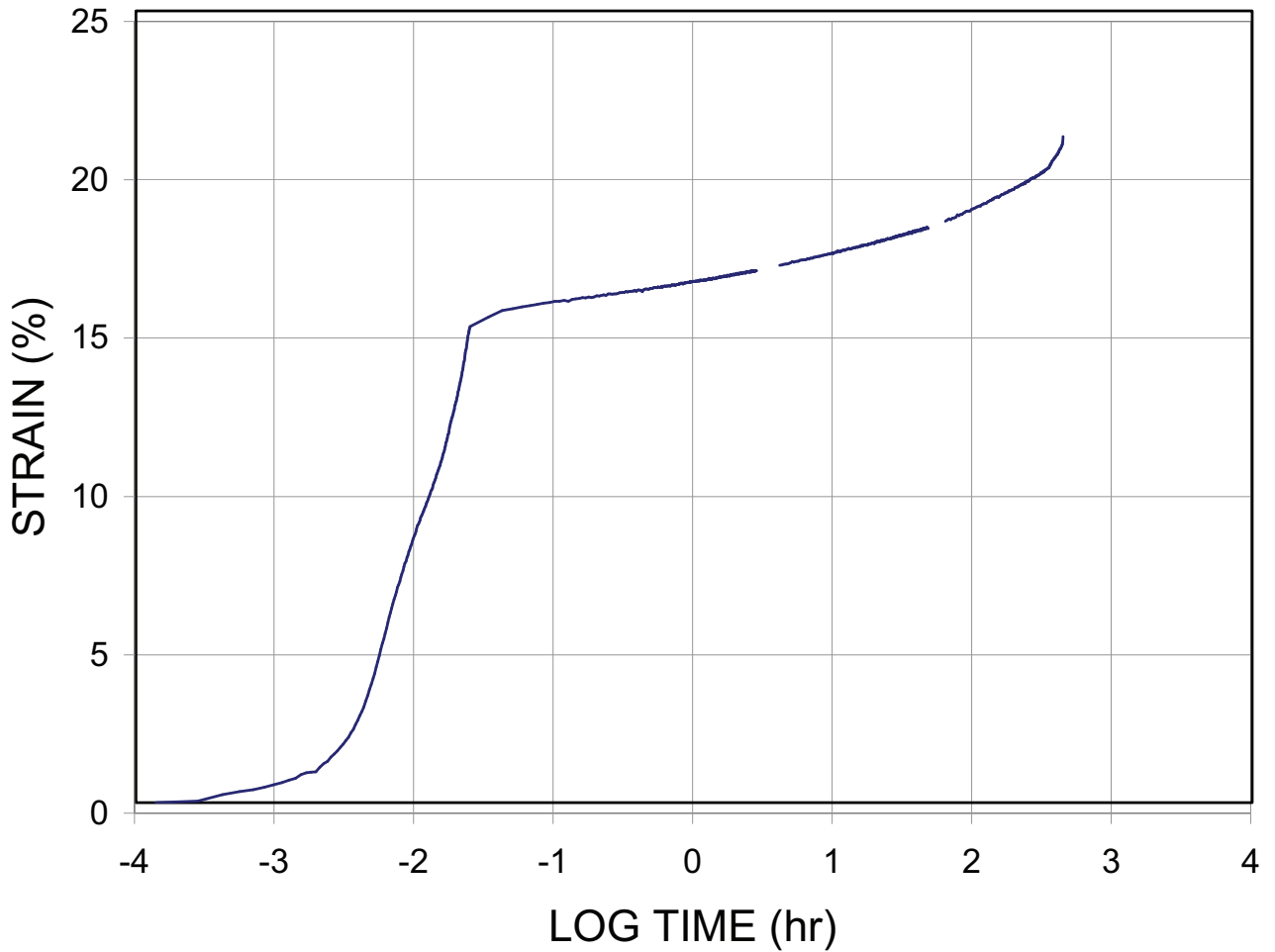


SUMMARY CREEP PARAMETERS: TEMA
200/30

Specimen: 688t6u200sim80 Test Date: 09-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.
 Average Creep Stress: 194.7 kN/m %UTS: 80.00
 Ultimate Tensile Strength: 243.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.27	-
2	9400	10021	621	0.1	1.2062	33.63	0.0840
3	19300	20011	711	0.1	1.1724	47.85	0.0824
4							
5							
6							

Summary	Initial	Final	Units	@20C refT	AVG
lab time	79	25951	sec	-	0.0832
logA _T (t-t')	1.8976	6.2015	log hours	2.5838	
A _T (t-t')	-	0.05	years	0.04	
Strain	13.672	21.036	%	-	
Modulus	1200.3	925.6	kN/m	-	



SUMMARY CREEP PARAMETERS: TEMA

200/30

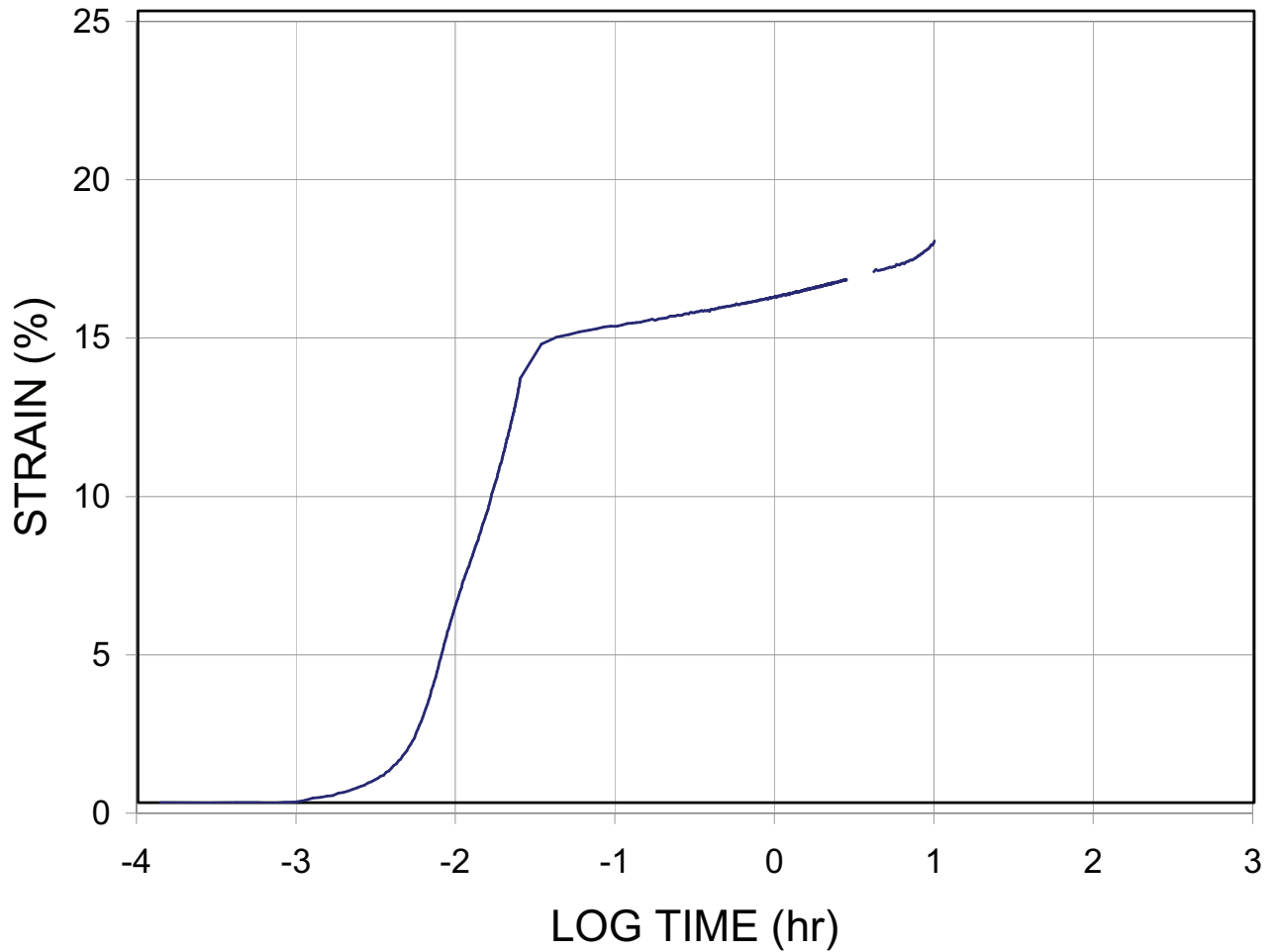
Specimen: 688t6u200sim85 Test Date: 16-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

Average Creep Stress: 206.9 kN/m %UTS: 85.00

Ultimate Tensile Strength: 243.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.48	-
2	9400	10022	622	0.1	1.2057	34.19	0.0820
3							
4							
5							
6							

Summary	Initial	Final	Units	@20C refT	AVG
lab time	79	11612	sec	-	0.0820
logA _T (t-t')	1.8976	4.5505	log hours	0.9516	
A _T (t-t')	-	0.00	years	0.00	
Strain	12.028	17.738	%	-	
Modulus	1269.9	1166.3	kN/m	-	



SUMMARY CREEP PARAMETERS: TEMA

60/30

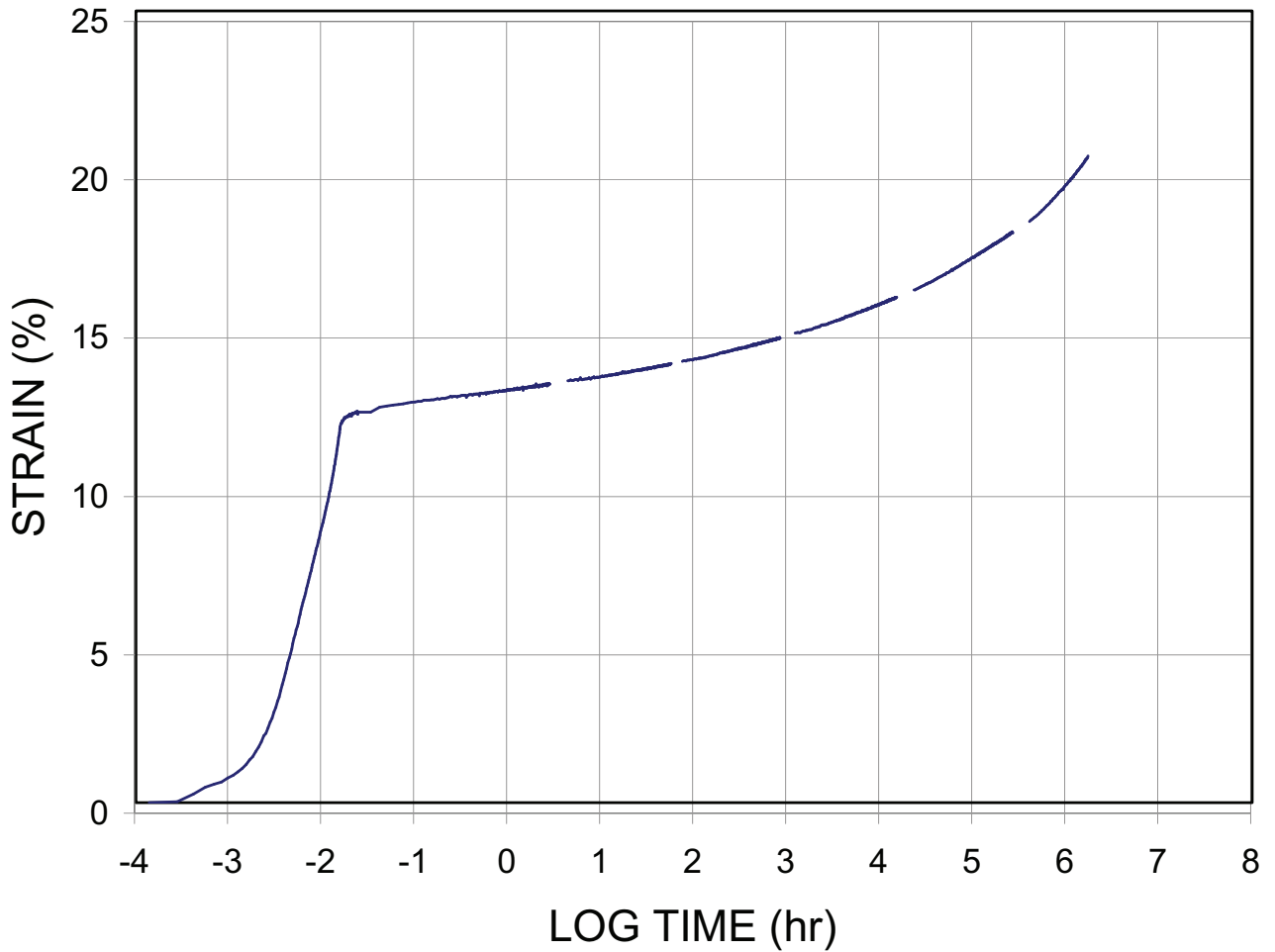
Specimen: 688t6u60sim70 Test Date: 13-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

Average Creep Stress: 58.4 kN/m %UTS: 70.01

Ultimate Tensile Strength: 83.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.57	-
2	9500	10020	520	0.12	1.2838	32.69	0.0979
3	19300	20010	710	0.1	1.1693	46.07	0.0874
4	29400	30000	600	0.14	1.2502	59.51	0.0930
5	39400	39990	590	0.14	1.2530	73.02	0.0928
6	49400	49980	580	0.18	1.2601	86.36	0.0944

Summary	Initial	Final	Units	@20C refT	AVG
lab time	78.14	53160	sec	-	
logA _T (t-t')	1.8929	9.7916	log hours	6.1936	
A _T (t-t')	-	196.12	years	178.16	
Strain	12.288	20.416	%	-	
Modulus	475.1	286.0	kN/m	-	



SUMMARY CREEP PARAMETERS: TEMA

60/30

Specimen: 688t6u60sim75 Test Date: 10-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

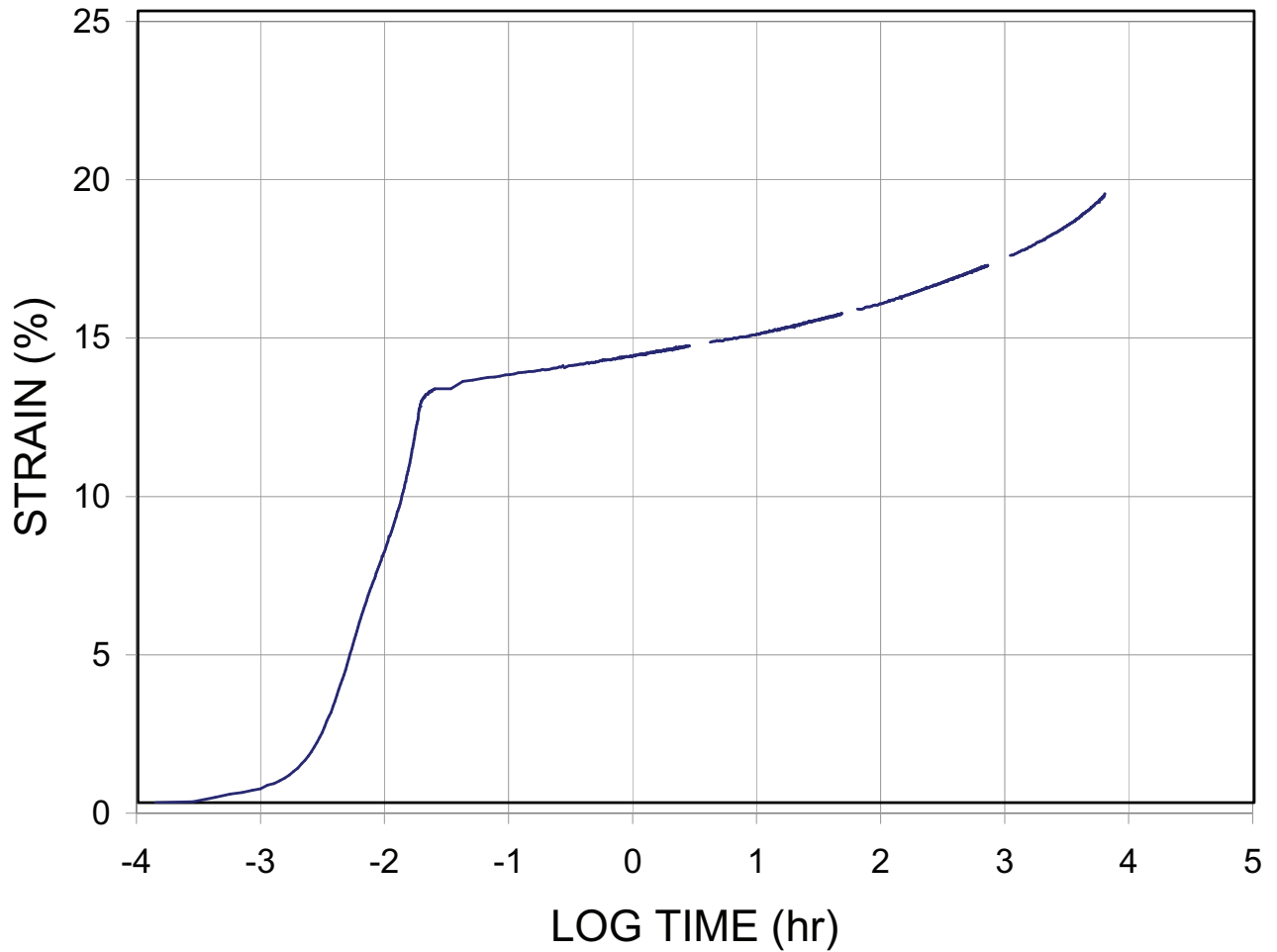
Average Creep Stress: 62.5 kN/m %UTS: 75.01

Ultimate Tensile Strength: 83.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.91	-
2	9400	10020	620	0.11	1.2071	32.46	0.0961
3	19300	20010	710	0.12	1.1732	45.81	0.0879
4	29300	30000	700	0.18	1.1830	59.01	0.0896
5							
6							

Summary	Initial	Final	Units	@20C refT
lab time	78.28	35460	sec	-
logA _T (t-t')	1.8937	7.3530	log hours	3.7878
A _T (t-t')	-	0.71	years	0.70
Strain	12.888	19.211	%	-
Modulus	485.5	325.6	kN/m	-

AVG 0.0911



SUMMARY CREEP PARAMETERS: TEMA

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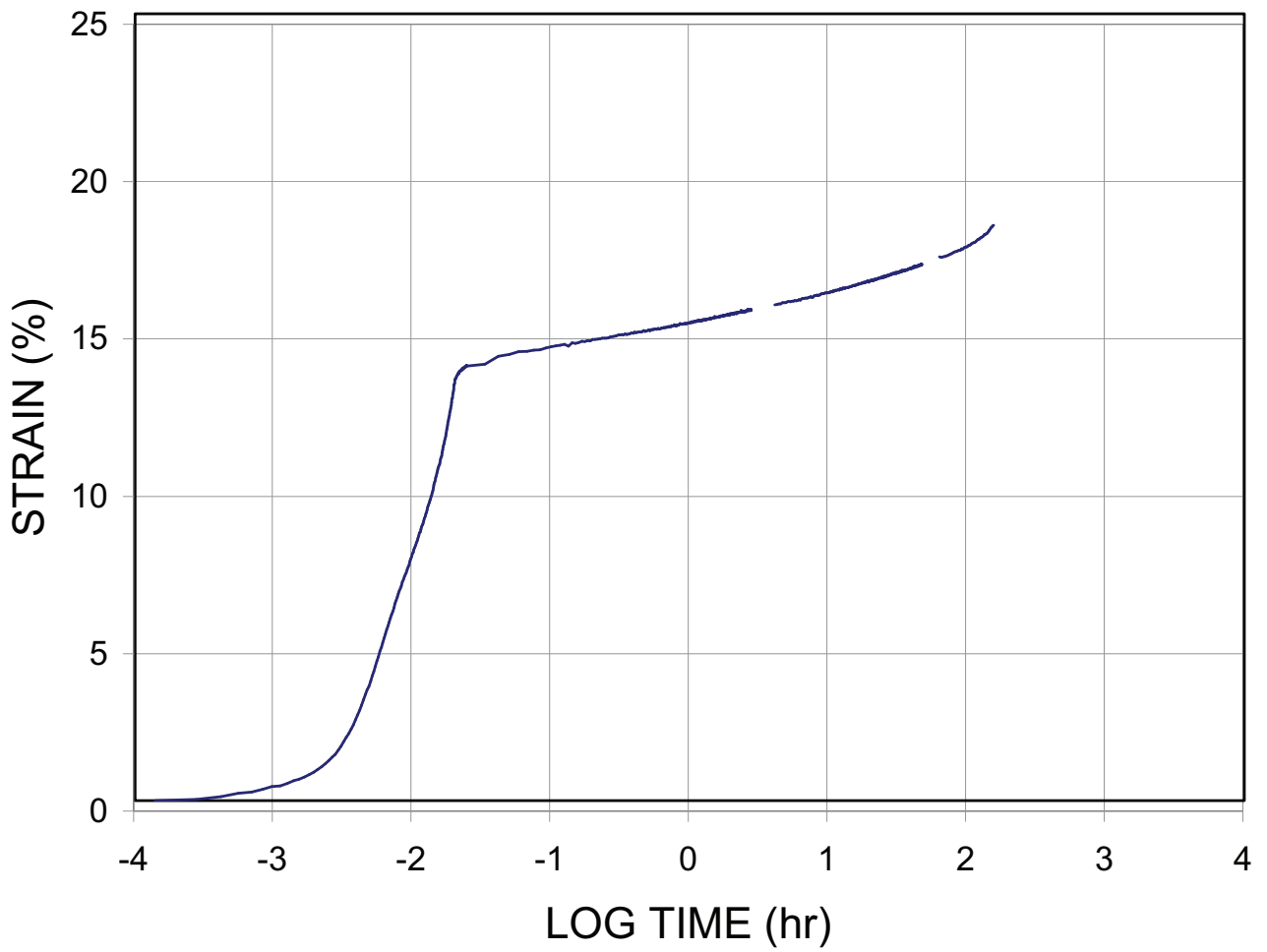
Specimen: 688t6u60sim80 Test Date: 14-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

Average Creep Stress: 66.7 kN/m %UTS: 80.00

Ultimate Tensile Strength: 83.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.33	-
2	9400	10020	620	0.05	1.2069	33.57	0.0847
3	19300	20010	710	0.05	1.1730	48.22	0.0801
4							
5							
6							

Summary	Initial	Final	Units	@20C refT	AVG
lab time	78.47	21630	sec	-	0.0824
logA _T (t-t')	1.8947	5.7474	log hours	2.1344	
A _T (t-t')	-	0.02	years	0.02	
Strain	13.631	18.284	%	-	
Modulus	489.8	364.9	kN/m	-	



SUMMARY CREEP PARAMETERS: TEMA

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Specimen: 688t6u60sim85 Test Date: 13-Feb-07 Method: SIM (10⁴s, 14C),single rib, machine dir.

Average Creep Stress: 70.9 kN/m %UTS: 85.00

Ultimate Tensile Strength: 83.4 kN/m Rupture: YES

Dwell Seq	t'	t	(t-t')	Vshift(%)	logA _T	Temp	logA _T /T
1	0	0.5	0.5	-	-	19.12	-
2							
3							
4							
5							
6							

Summary	Initial	Final	Units	@20C refT	AVG
lab time	78.1	5670	sec	-	0.0000
logA _T (t-t')	1.8927	3.7536	log hours	0.1973	
A _T (t-t')	-	0.00	years	0.00	
Strain	13.618	17.411	%	-	
Modulus	522.0	407.1	kN/m	-	

