Technical Information

Composite Conductor

1272-kcmil

Derivation of Power-Law Creep Parameters

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<u>1272-kcmil 3M™ Composite Conductor: Derivation of Power-Law Creep Parameters</u>

<u>Summary</u>

Creep Testing was performed at room temperature on 1272-kcmil 3M™ Composite Conductor (also known as ACCR – Aluminum Conductor Composite Reinforced). The work was carried out by NEETRAC and is summarized in a report entitled, "1272-kcmil, 3M™ Composite Conductor Room-temperature Creep", NEETRAC Project Number: 03-068, September 2003. The data from that study is used here to generate the creep equations governing the creep behavior of the conductor.

<u>Creep Data:</u>

The raw data was obtained from NEETRAC in the form of Microsoft Excel® Spreadsheets, and all the subsequent analysis was performed using Microsoft Excel® Software. The specification for the 1272-kcmil Conductor is provided in Appendix A. Data from each testing load was plotted in a graph of Creep Strain vs. Time (Figure 1-4), using creep strains that have been corrected for load and temperature drift (see original test report noted above). This data was selected from one hour onwards since the first hour of creep can often be influenced by a variety of effects (time to load, conductor sample preparation, etc.). The target time for the creep test was 1000 hours, although often this time was exceeded depending on the availability of the test equipment. Power-law curve fits are made to the data and the resulting equations are compiled in Table 1, which relate creep strain (y) to time (x) for each loading (%RBS) condition.

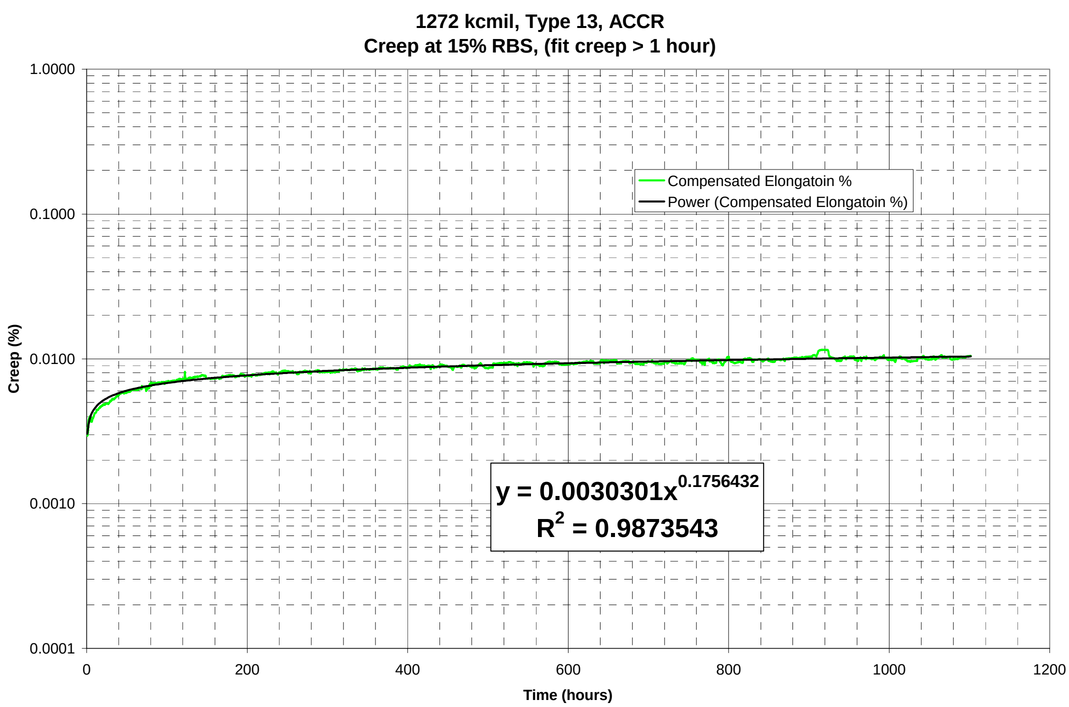

Figure 1. Creep strain vs. time for 1272-kcmil conductor at 15% RBS load

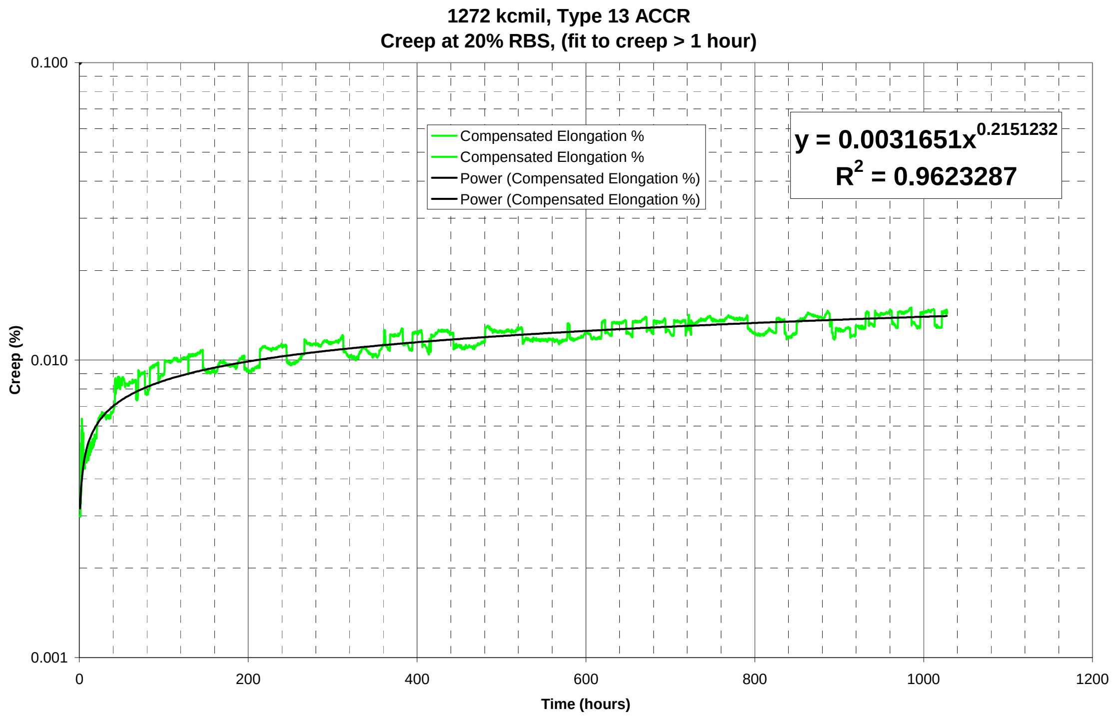

Figure 2. Creep strain vs. time for 1272-kcmil conductor at 20% RBS load

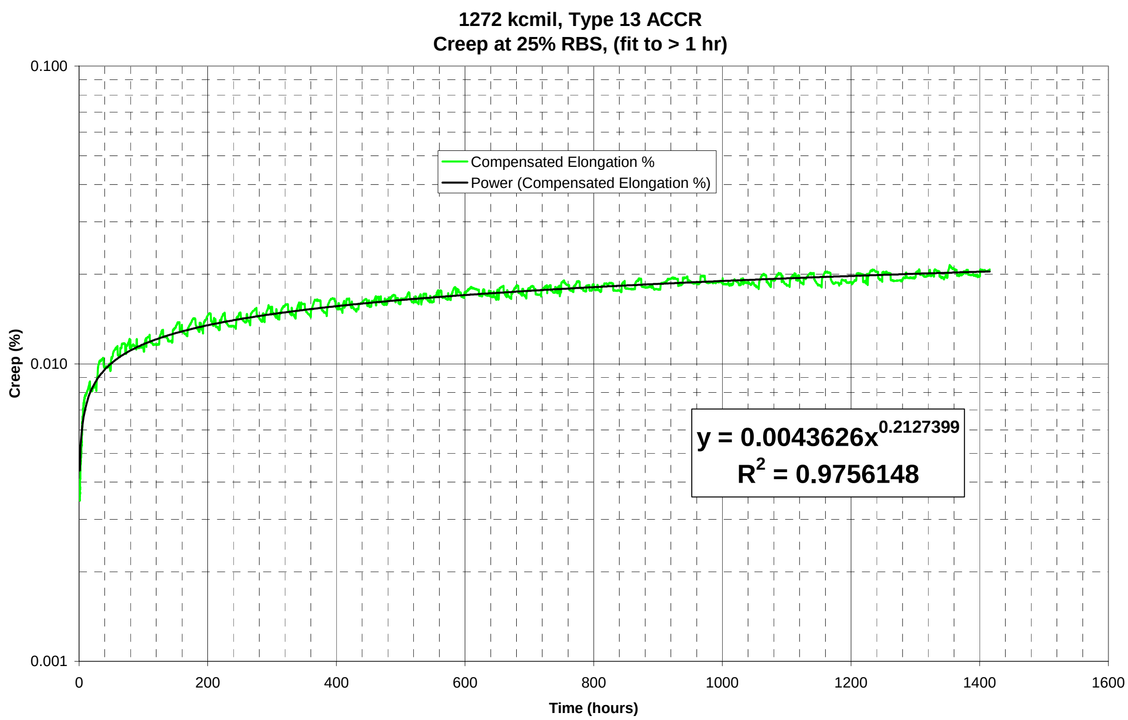

Figure 3. Creep strain vs. time for 1272-kcmil conductor at 25% RBS load

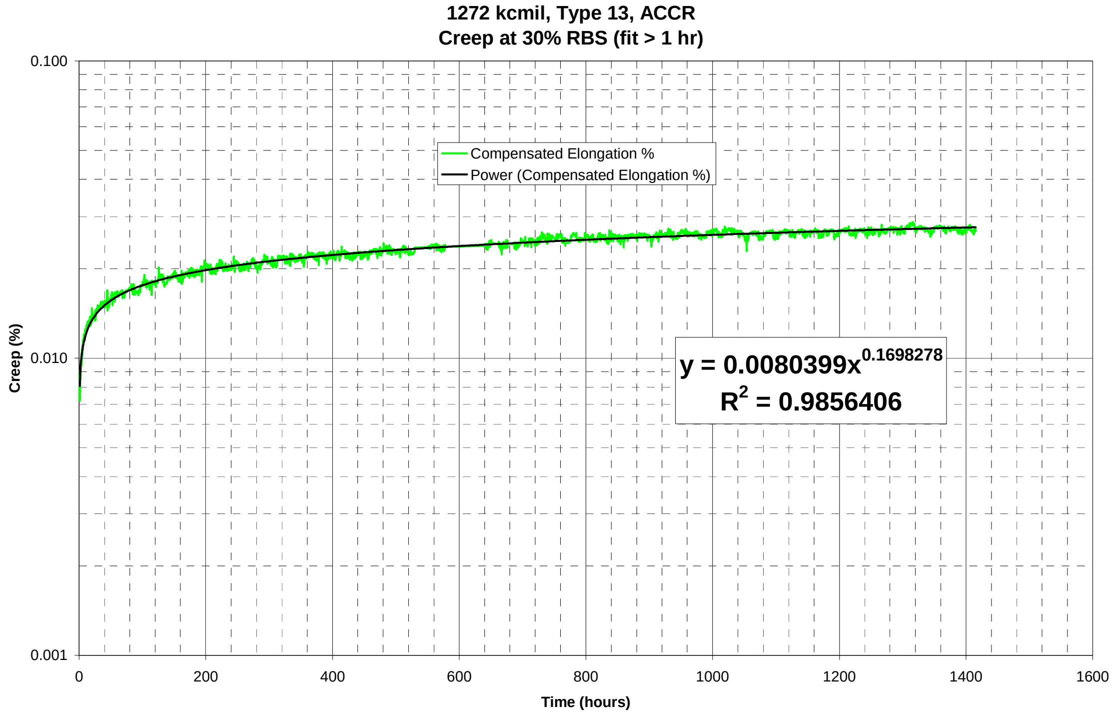

Figure 4. Creep strain vs. time for 1272-kcmil conductor at 30% RBS load.

Load (%RBS)	Fitting Equation	Correlation Coefficient
15%	$y = 0.0030301\ x^{0.1756432}$	$R^2 = 0.987$
20%	$y = 0.0031651\ x^{0.2151232}$	$R^2 = 0.962$
25%	$y = 0.0043626\ x^{0.2127399}$	$R^2 = 0.976$
30%	$y = 0.0080399\ x^{0.1698278}$	$R^2 = 0.986$

Table 1. Summary of Fitting Equations (in the form y (%) = b*[(x in hrs)^c])

Examining the data in Table 1, the coefficients of the fitting equations seem reasonably well behaved. The power term varies from 0.17-0.21, which creates some scatter, since this term does not usually vary with stress. The first term before the abscissa usually increases with stress, and this progression is observed although the parameter at the 15% load level is close to the 20% value and the value for 30% load is then much higher than the 25% load level. A smoother progression would perhaps be expected.

Self-Consistency of Creep Data:

Creep data is notoriously difficult to generate experimentally due to variations in both samples and test procedure. Plotting the fitting equations on a single graph yields Figures 5 and 6, which are extrapolated out to 100,000 hours to check for sensible behavior in the extrapolation. This data is used to predict the 10-year (87,600 hours) creep behavior of the conductor. In Figure 5, the curves are reasonably uniformly spaced suggesting the relative long-term creep behavior is reasonably captured, although the 30% RBS curve seems to be relatively closer to the 25% RBS curve suggesting some small under-prediction.

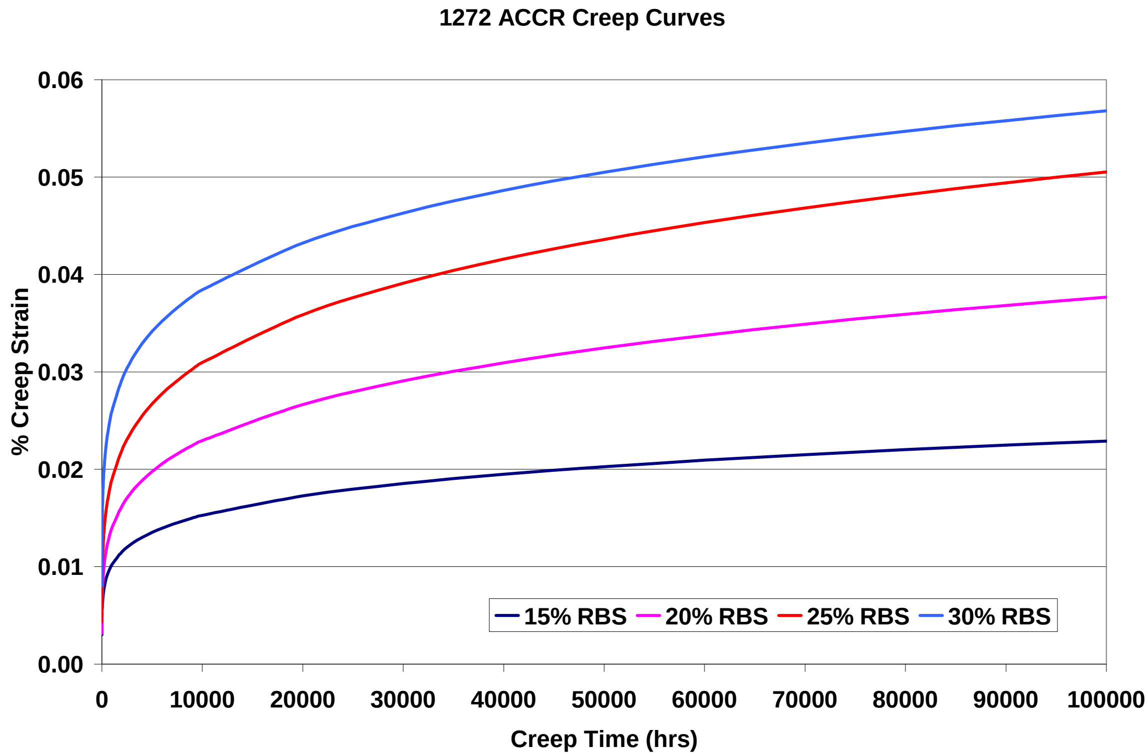

Figure 5. Creep strain vs. time for 1272-kcmil conductor at all test loads

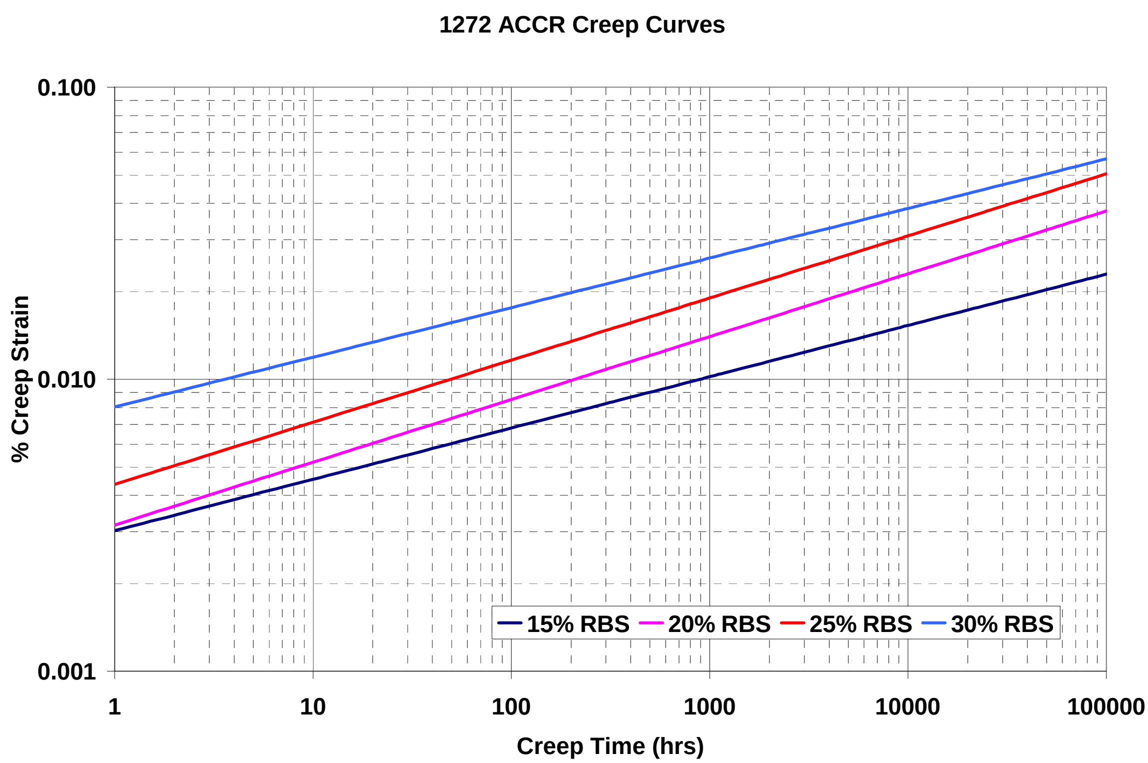

Figure 6. Log. Creep strain vs. Log. time for 1272-kcmil conductor at all test loads

In a log-log plot in Figure 6, an ideal behavior would have parallel lines for each stress level. For this data set, the line for 15% RBS load is close to the 20% RBS load data at short times (<10 hours, suggesting an over estimation of creep for the 15% RBS load for short times. At longer times, the 30% RBS line appears to slightly under-predict the creep as noted above. However, overall the deviations are small and would be expected from the nature of creep data. Thus this data seems to be a good quality set for predicting the long-term creep.

Initial Loading Condition:

One cause for discrepancies in creep data can be during the initial loading phase. Data from this phase is presented for each loading condition in Figures 7-10 for comparison.

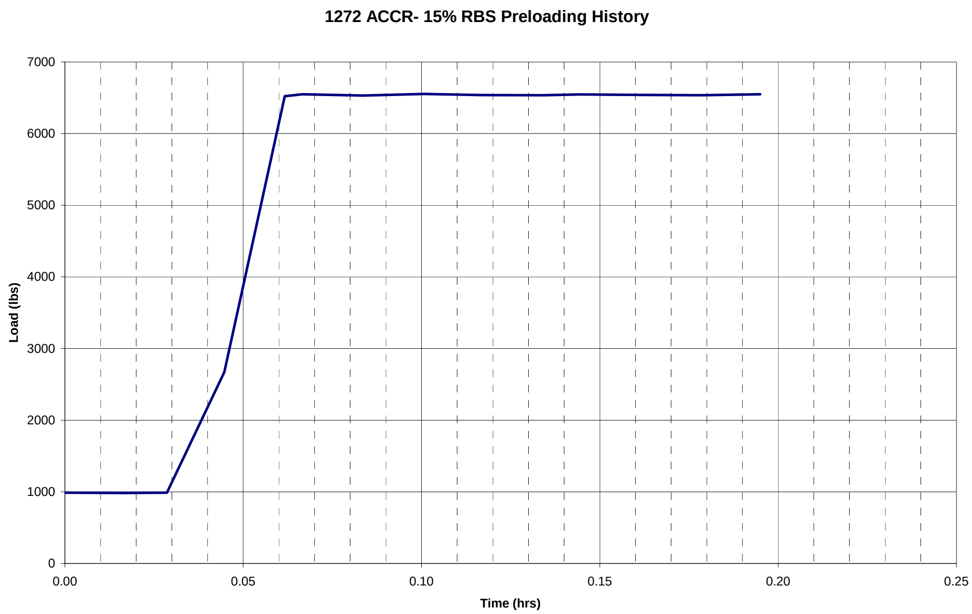

Figure 7. 15% RBS initial loading. Load was increased to target load in 2 minutes.

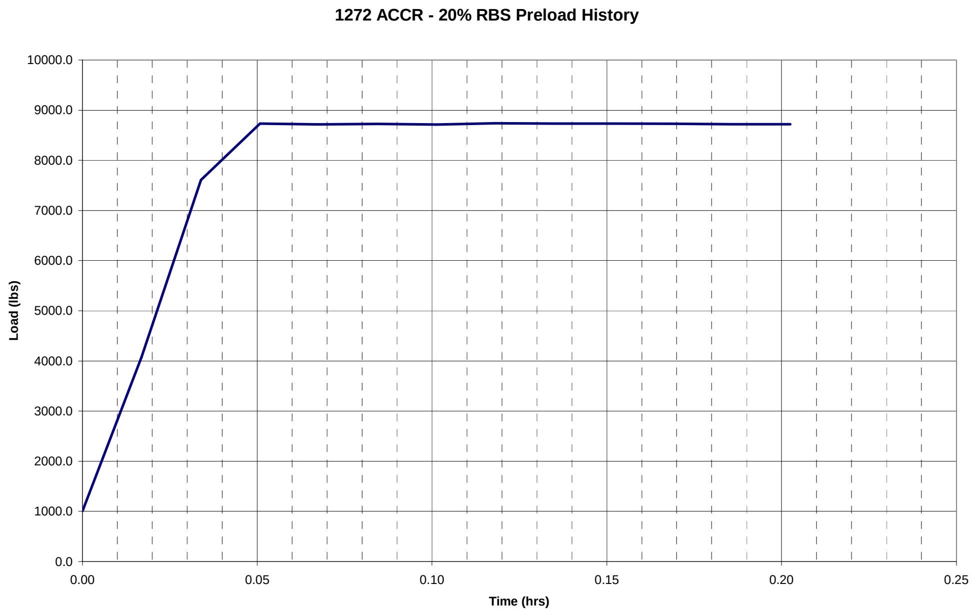

Figure 8. 20% RBS initial loading. Load was increased to target load in 3 minutes.

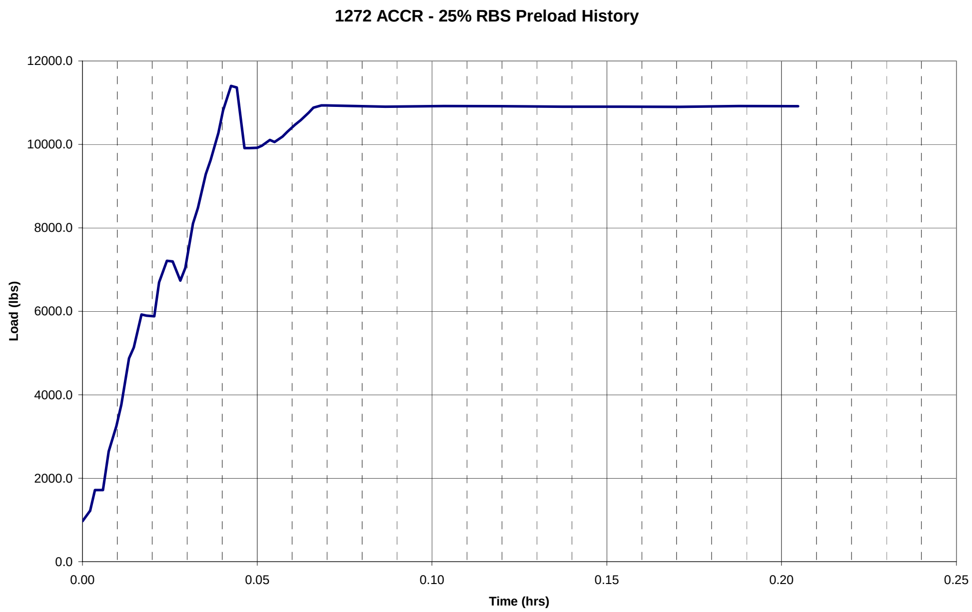

Figure 9. 25% RBS initial loading. Load was increased to target load in 4 minutes.

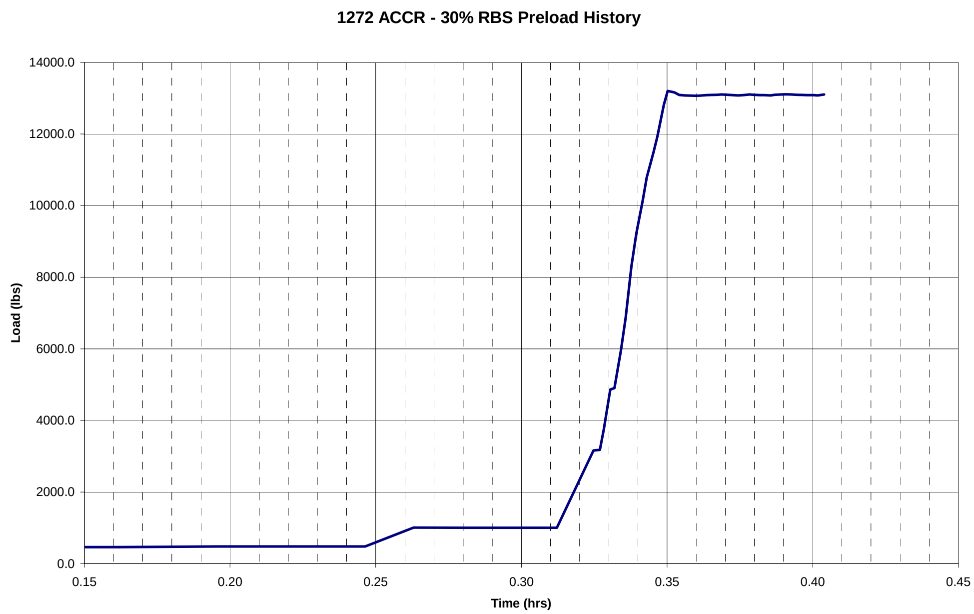

Figure 10. 30% RBS initial loading. Load was held at approx. 1000 lbs for 20 minutes and then increased to target load in 2.5 minutes.

Overall, there is little difference in load ramp time, and load pre-history, and so no reason to suggest any significant effects of the resulting creep data.

Creep Stress-Strain Curves

The creep behavior is used to generate stress-strain curves for the conductor after 6 months, 1-year and 10-years of creep. Using the creep equations in Table 1, the creep strain at each stress level is generated for each of the time intervals. These creep strains are then added to the strain from the inherent stress-strain behavior for each stress level. The latter strain is derived in a 3M Technical Report entitled, "1272-kcmil 3M Composite Conductor: Stress-Strain Polynomial Coefficients for Design Software", August 2005. The conductor stress-strain behavior is given by the following 4th order polynomial equation relating stress (y) in psi to % strain (x);

y = 7606.8x4 - 14650x3 - 35615x2 + 89832x

The creep strains and total conductor strains are given in Table 2.

Stress (psi)	Initial Strain (%)	6-mo creep strain	1-yr creep strain	10-yr creep strain	Total 6-mo strain	Total 1-yr strain	Total 10-yr strain
5819	0.06658	0.0132	0.0149	0.0224	0.0798	0.0815	0.088945
7758	0.08966	0.0192	0.0223	0.0366	0.1089	0.1120	0.126273
9697	0.11325	0.0260	0.0301	0.0491	0.1392	0.1433	0.162365
11638	0.13744	0.0334	0.0376	0.0555	0.1708	0.1750	0.1930

Table 2. Creep strains with time and total strains for stresses used in creep tests

For each creep time, the total strain is plotted and then curve-fit using a 2nd-order polynomial equation with a zero intercept. An example for the 6-month creep is given in Figure 11.

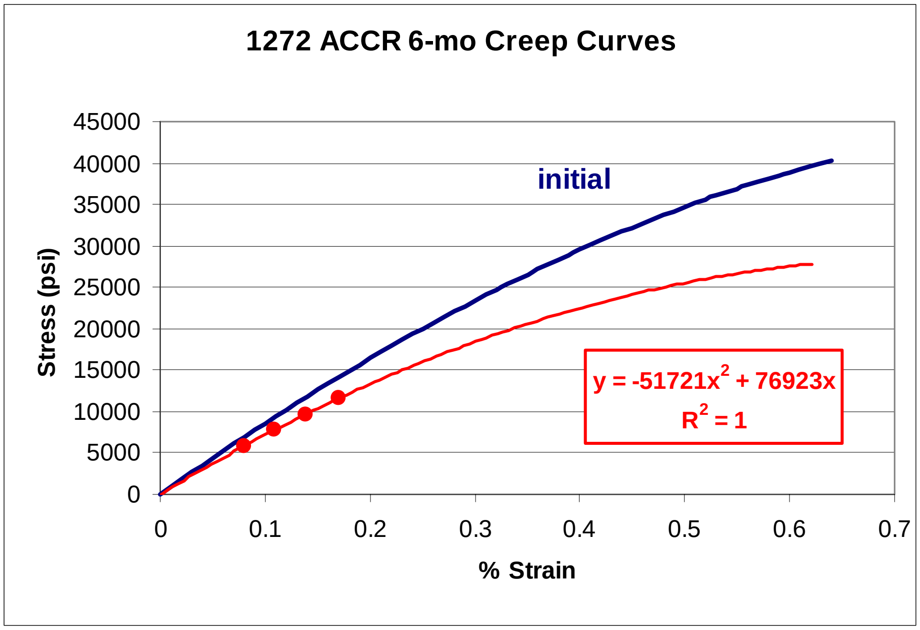

Figure 11. Six-month creep curves for 1272-kcmil 3MTM Composite Conductor

The stress-strain equations for different creep times are summarized in Table 3.

Creep Time	Creep Stress-Strain Equation
0	y = 7606.8x4 - 14650x3 - 35615x2 + 89832x
6 months	y = -51721x2 + 76923x
1 year	y = -48772x2 + 74899x
10-years	y = -36759x2 + 66760x

Table 3. Creep Stress-strain curves for 1272-kcmil 3MTM Composite Conductor

These equations are plotted in a summary form in Figure 12.

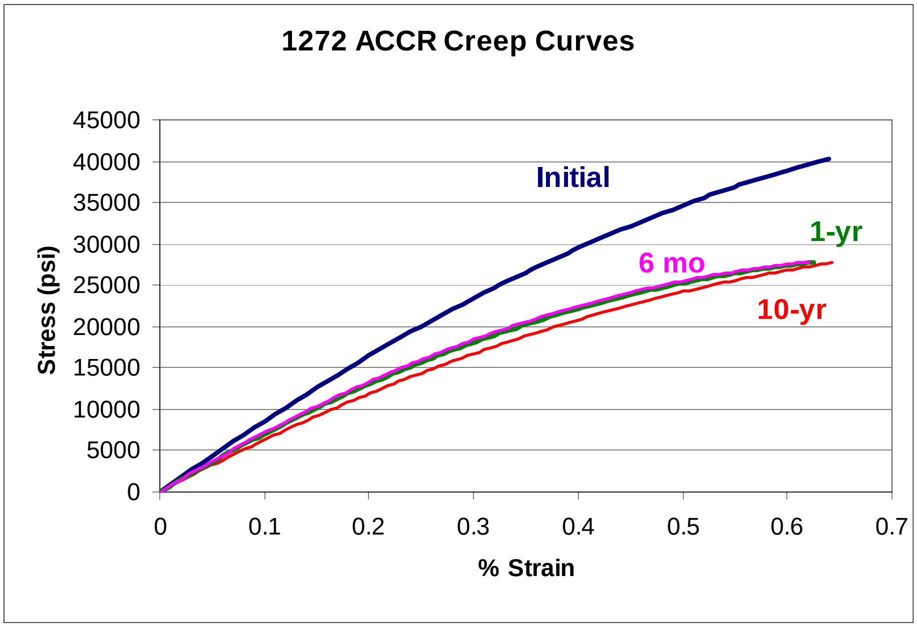

Figure 11. Creep Stress-Strain Curves for 1272-kcmil 3M™ Composite Conductor

Conclusion:

Creep data from 1272-kcmil 3M™ Composite Conductor reported was re-analyzed using a standard methodology and checked for consistency. The resulting power-law creep equations fit a form of:

a (%) = b*[(hrs)^c] where b and c are constants and a is the creep strain

The creep parameters are summarized in Table 2.

Load (%RBS)	Stress (psi)	b	c
15	5819	0.00303	0.175643
20	7758	0.003165	0.215123
25	9697	0.004363	0.21274
30	11638	0.00804	0.169828

Table 2. Summary of Creep Parameters for 1272-kcmil Conductor

Acknowledgement:

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Disclaimer:

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.

Appendix A: 1272-kcmil, 3M™ Composite Conductor Specification

Conductor Physical Properties		
Designation		1272-T13
Stranding		54/19
kcmils	kcmil	1,272
Diameter		
indiv Core	in	0.092
indiv Al	in	0.153
Core	in	0.46
Total Diameter	in	1.38
Area		
Al	in^2	0.999
Total Area	in^2	1.126
Weight	lbs/linear ft	1.392
Breaking Load		
Core	lbs	23,622
Aluminum	lbs	20,055
Complete Cable	lbs	43,677
Modulus		
Core	msi	31.4
Aluminum	msi	8.0
Complete Cable	msi	10.6
Thermal Elongation		
Core	10^-6/F	3.5
Aluminum	10^-6/F	12.8
Complete Cable	10^-6/F	9.2
Heat Capacity		
Core	W-sec/ft-C	28
Aluminum	W-sec/ft-C	520

Conductor Electrical Properties		
Resistance		
DC @ 20C	ohms/mile	0.0700
AC @ 25C	ohms/mile	0.0717
AC @ 50C	ohms/mile	0.0787
AC @ 75C	ohms/mile	0.0858
Geometric Mean Radius	ft	0.0466
Reactance (1 ft Spacing, 60hz)		
Inductive Xa	ohms/mile	0.3720
Capacitive X'a	ohms/mile	0.0847