Temperature cycling simulation using finite element analysis

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Abstract

Temperature cycling is a key component in fiber optic cable qualification. The combination of coefficient of linear thermal expansion (CLTE), excess fiber length (EFL), and subunit free space determine the success of the qualification (and installed use) for dry loose tube type cables. This paper explores the use of finite element analysis (FEA) simulation to screen designs for material selection and dimensions.

The specific parameter under investigation in this paper is the FEA simulation with focus on the strain on the fibers and how it relates to attenuation. The simulation was within SolidWorks and a comparison was drawn between that and empirical temperature cycle attenuation measurements. EFL was introduced into the simulation based on empirically measured samples on the bench.

Keywords: Temperature; Simulation; FEA; Fiber; Attenuation; Excess Fiber Length; EFL; Coefficient of Linear Thermal Expansion; CLTE;

1. Introduction

Finite Element Analysis (FEA) has become a useful tool to model new designs and determine the direction of changes for actual build and test samples. In this paper, we are using FEA in SolidWorks Simulation to demonstrate the effects of the Coefficient of Linear Thermal Expansion (CLTE) on fiber optic subunits. We were able to estimate how much strain is being exerted on fibers by the other fibers and the jacket due to the high temperature-dependent shrinkage of the plastic subunit material and low shrinkage of the glass fiber.

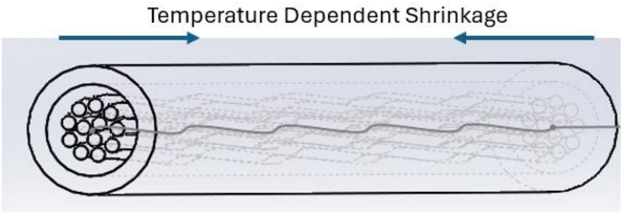


Figure 1. Jacket CLTE effect on optical fiber

2. The Simulation

2.1 Excess Fiber Length (EFL)

EFL is the amount of fiber in the subunit beyond the linear length of the subunit jacket that allows the fiber to be at minimal strain when the subunit is pulled. EFL is initially established as a balance of fiber tension and trough shrinkage during the extrusion of the subunits.

EFL was measured on two samples post extrusion on the bench to determine the EFL value to use in the simulations. Multiple iterations were run with the measured EFL values to see the effects at cold temperature.

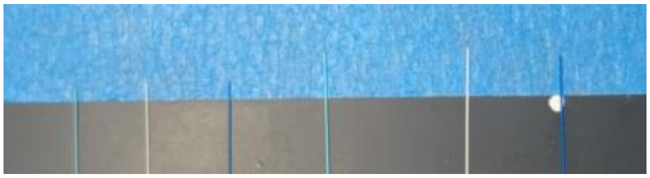
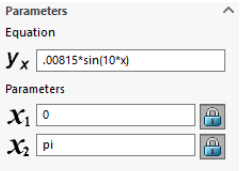


Figure 2. Bench measured EFL

The simulation fiber with EFL was created using the equation driven line and the length of the fiber was estimated using the Pythagorean Theorem ($A^2 + B^2 = C^2$).



Parameters
Equation
y_x .00815*sin(10*x)
Parameters
x_1 0
x_2 pi

Figure 3. Equation driven line formula in SolidWorks to produce EFL

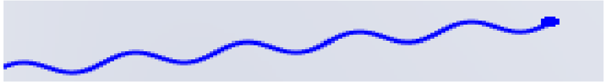


Figure 4. Equation driven line in SolidWorks to produce simulation fiber with EFL

Table 1. Method used to determine amplitude for equation driven line from EFL

	0.00815*sin(10*x)	0.00925*sin(10*x)
Linear Length	3.1416	3.1416
Periods	5.0000	5.0000
Amplitude	0.00815	0.00925
a	0.00815	0.00925
b	0.1571	0.1571
c	0.1573	0.1574
Length of Wave	3.1458	3.1470
EFL	0.135%	0.173%

2.2 Coefficient of Linear Thermal Expansion (CLTE)

CLTE is the amount of shrinkage or expansion along the length of an item due to temperature change. The plastic subunit jacket has a relatively high CLTE in comparison to the glass fiber. As the temperature is lowered the plastic subunit jacket gets shorter and makes the glass fiber inside more wavy which creates more light loss in the fiber (attenuation).

The optical fiber CLTE value used for the simulation was a generic property of glass. The CLTE value for the subunit jacket was empirically determined by adhering the fiber to the subunit jacket at one end of a short sample and measuring the fiber protrusion at the other end at low temperature. The fiber protrusion length equals the amount of subunit change in length. Measuring the fiber protrusion with all of the components in place (fiber, aramid yarn) provides the most realistic CLTE behavior.

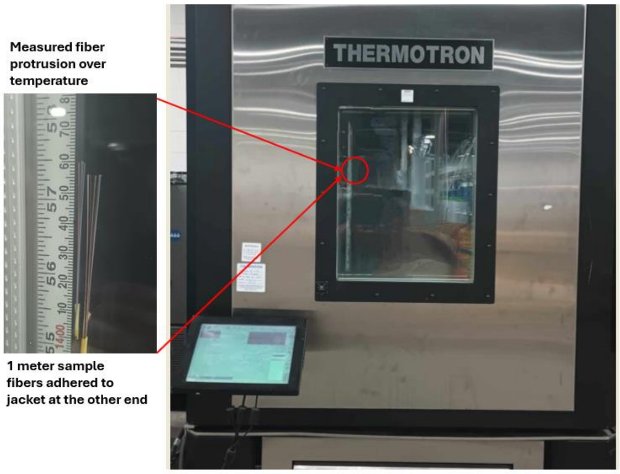


Figure 5. Fiber protrusion measurement at low temperature

Table 2. CLTE calculation per below formula

ΔL (mm)	5
L0 (mm)	1000
ΔT (°C)	63
CLTE (α)	0.000079

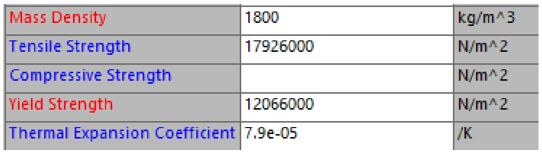
$\alpha = \Delta L / (L0 * \Delta T)$

α: is the coefficient of linear expansion per degree Kelvin

ΔL: change in length

L0: is the original length

ΔT: is the change in temperature



Mass Density	1800	kg/m^3
Tensile Strength	17926000	N/m^2
Compressive Strength		N/m^2
Yield Strength	12066000	N/m^2
Thermal Expansion Coefficient	7.9e-05	/K

Figure 6. Thermal expansion coefficient input into simulation

2.3 Simulation Setup

Numerous iterations of the setup were tried, the most realistic iteration is represented below. The cable is a 2.3mm OD subunit with 12 fibers. It is 3.14 inches long to simulate a section of cable in the middle of a reel that the fibers are locked in and cannot protrude out of the jacket. Pi was chosen for a length to get the fibers to oscillate full periods.

The fibers follow an equation driven line that equates to 0.135% and 0.173% EFL to represent the samples measured on the bench. No aramid yarn was used in the assembly because a way to accurately represent the properties of the aramid yarn was not found.

The fiber and jacket end faces are "fixed" at one end in the simulation. The fiber and inner jacket surface have a "no penetration" contact set. A thermal load of -40°C is applied to all surfaces. The assembly is "meshed" so that no node is larger than 0.005 inches.

2.4 Simulation Results

The simulation was run with the jacket on but was hidden in the results image below to be able to see what is happening with the fibers.

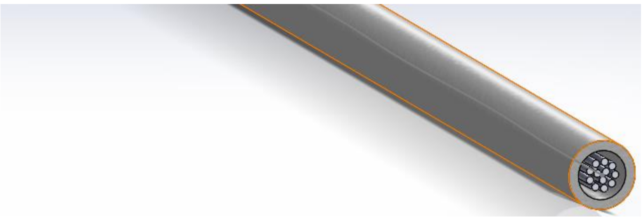


Figure 7. Simulation model with jacket

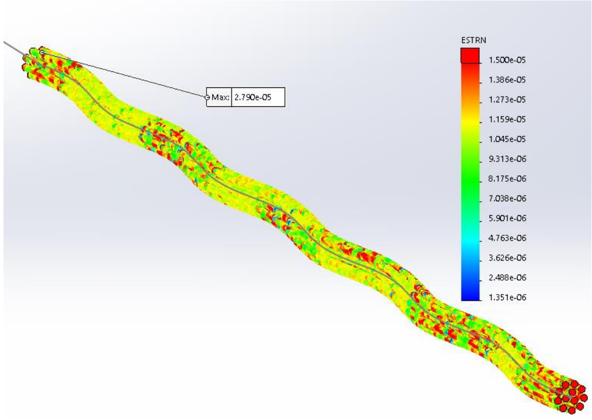


Figure 8. Simulation Results 0.135% Starting EFL with fibers compressed due to jacket CLTE

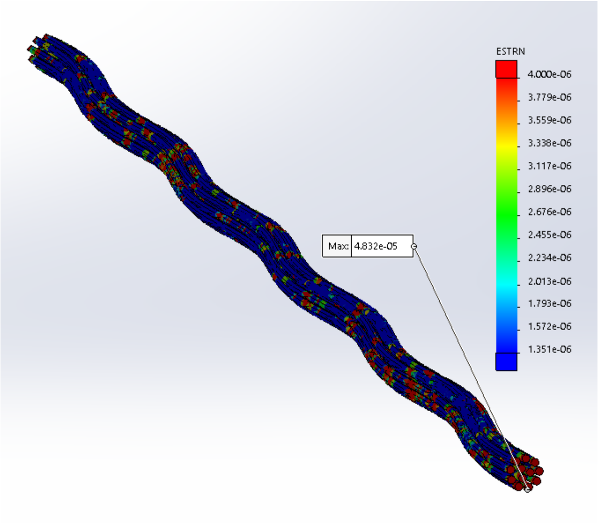


Figure 9. Simulation Results 0.173% Starting EFL with fibers compressed due to jacket CLTE

Results

Starting Avg. EFL was empirically measured on the bench to determine the percent EFL. Percent EFL was then back calculated to determine the equation driven line that the fibers follow in the cable. **Max Strain** is the resultant output from the simulation. The color scale was modified to differentiate the low and high strain areas and remove the scale influence of the jacket. The **Avg. Attn Change @ (-40C)** is the attenuation change in dB/km from 23°C and -40°C.

Higher initial EFL results in higher strain which drives higher attenuation change at -40°C.

Table 3. Strain and attenuation results

	Sample 1	Sample 2
Starting Avg. EFL	0.135%	0.173%
Max Strain	0.00279%	0.00483%
Avg. Attn Change @ (-40°C)	0.565	1.028

3. Conclusions

A working model of CLTE related to fiber optic loose tube cable is achievable in SolidWorks Simulation. Further validation to empirical test results is necessary to be able to make sound decisions on cable design. The two most valuable screening variables that this simulation provides are jacket material selection for low CLTE and cable inside diameter.

Determining model material properties for aramid yarn will make the model more accurate as well as lend itself to other simulations including tensile. The fibrous nature of aramid with high tensile and no compression strength makes it a challenge to model.

4. Acknowledgments

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5. Pictures of Authors

Henry Rice is a Fiber Applications Engineer / Principal Product Engineer at Proterial Cable America. He holds a B.Sc degree in Industrial Technology from the University of Southern Maine and a Masters of Business Administration from the Massachusetts College of Liberal Arts. He has 17 years of fiber optic cable design, development, and manufacturing experience in addition to 14 years of communication cable installation and maintenance experience with the U.S. Air Force. Henry Rice, 900 Holt Ave., Manchester NH 03109. Henry.Rice@usa.Proterial.com

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