COSTAR optical bench CTE testing

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ABSTRACT

Positioning and maintaining alignment of the corrective optics for the Space Telescope is the objective of the COSTAR Optical Benches. The fixed and deployable Optical Benches are graphite/epoxy structures to achieve the alignment requirements. The optical benches are comprised of various cross section tubes and flat panels. Layups are designed to meet specific material properties, one of which is near zero CTE. Precision CTE measurements are necessary to ensure mission success. Eastman Kodak performed all developmental and acceptance CTE testing of the COSTAR optical benches.

The apparatus used to perform the precision CTE measurements is described. Three test sets were used. A laser based, single coupon test set and a multiple coupon LVDT based system performed the coupon tests. A proprietary Universal Tube Tester was used to measure the CTE of 80" rhomboid cross section tubes for flight use. Uncertainties of 0.02 ppm/°F were achieved. Typical COSTAR test results are discussed, including graphical data for all three test configurations.

1.0 INTRODUCTION

There is an ever increasing demand for zero or near zero coefficient of thermal expansion (CTE) materials for use in both industrial and commercial applications. Often, it is imperative that the CTE of the material be precisely known. Various ultra low CTE graphite epoxy laminates have been designed, developed and used.

Due to the thermal stability specifications, the Corrective Optics Space Telescope Axial Replacement (COSTAR) optical benches required ultra low CTE layups (see Figure 1). An example of the stringent requirements were CTE specifications of 0.0±0.05 ppm/°F on the Deployable Optical Bench triangular tubes. The other components had similarly tight performance specifications. This level of precision made CTE verification testing a necessity during all the developmental and acceptance testing.

Three different CTE measuring devises developed at Eastman Kodak were used to perform these precise measurements. They were a laser based Coupon CTE Test Set, a linear variable differential transformer (LVDT) based Fast CTE Test Set, and another laser based Universal Tube Tester. Each piece of equipment was developed for different test configurations and have been operational for up to seven years. All the test sets will be described and typical COSTAR test results presented.

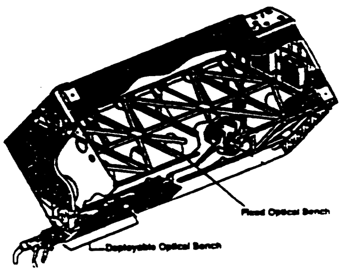

Figure 1 COSTAR Optical Benches

0-8194-1247-3/93/$6.00

2.0 COUPON CTE TEST SET

The Coupon CTE Test Set is patented under United States patent #4,924,477. The design is based on a Hewlett Packard HP5526A Laser Measurement System. Innovative coupon supports, custom algorithms and precision design facilitate the 0.02 ppm/F total uncertainty.

The coupon support assembly positions the coupon between the two mirrors in the coupon supports (see Figure 2). The coupon supports use four invar flexures to ensure pure horizontal movement of the mirrors which the coupon registers against. Each support hangs from a rail assembly. The rail assembly facilitates loading and unloading the coupons. The rails are affixed to the inner wall of a aluminum, double walled chamber.

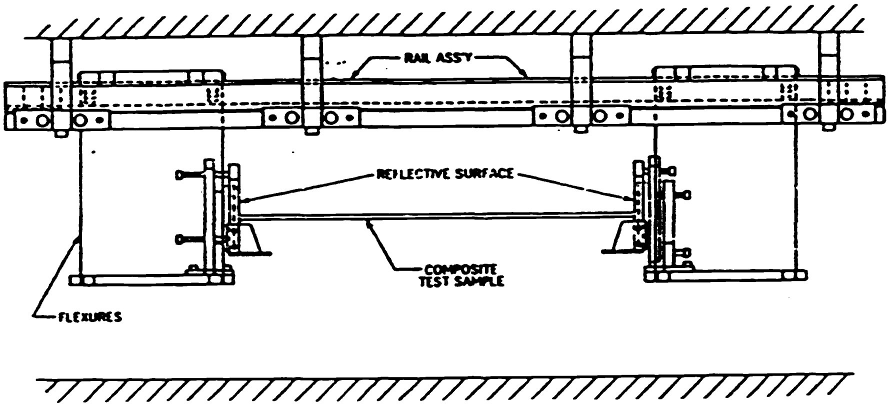

Figure 2 Coupon Support Assembly

The interferometric system consists of seven components (see Figures 3 and 4):

1) Hewlett Packard (HP) Helium-Neon Laser Head
2) HP Laser display Unit
3) Dilatometer Converter
4) HP Remote Interferometer
5) HP Retroreflectors
6) HP Plane mirror Converter
7) Reflective mirrors on the coupon supports

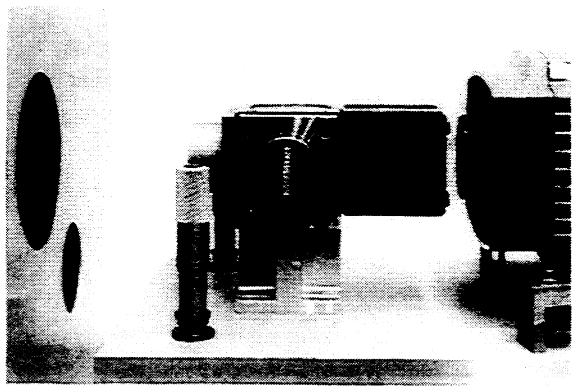

Figure 3 and 4 Interferometric System

The measurement of coupon length change is made with the HP laser head and display unit. The laser head emits a two frequency laser beam. The two frequencies are separated from each other by filters in the dilatometer converter. One frequency passes through the remote interferometer and reflects off the first mirror back into the interferometer and dilatometer converter, which reflects the beam off the first mirror again, at a position 180 degrees from the initial reflection. The other frequency follows a similar path, except it passes through the nonreflective parts of the first mirror and reflects off the second mirror twice. Both of the frequencies return to the laser head (see Figure 5). As the mirrors are moved, due to coupon expansion and contraction, the laser detects the frequency shifts, converts the shifts into displacements, and subtracts one mirror displacement from the other to calculate the relative displacement between the two mirrors. This is twice the coupon's length change.

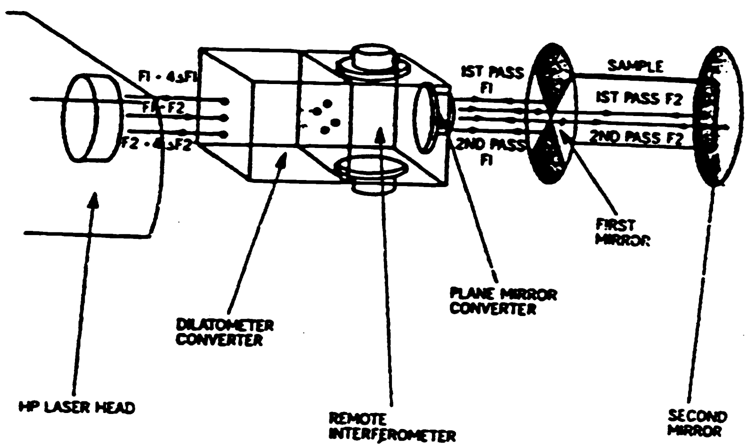

Figure 5 Coupon Test Set Optical Ray Trace

All of the test set components were designed or purchased to minimize possible errors. The following design features contribute to this goal:

* the chamber is aluminum and insulated to provide a uniform temperature
* the coupon supports have flat mirrors suspended by four thin invar flexures. The four flexure supports minimize mirror tilt.
* any tilt that occurs will be canceled by the opposing effects of the multipass system
* the coupon supports, optical mounts, and flexures are made of invar to minimize distortion and associated errors
* thermistors used for coupon temperature measurement are accurate to 0.2°F

Computer data acquisition and control algorithms were developed for automatic testing. The operator inputs the coupon length and test parameters and starts the test. A minimum of three hours of vacuum preconditioning is required prior to testing. This allows the coupon to sufficiently dry out so the hygroscopic shrinkage will be low and relatively linear during the test period. Any remaining shrinkage is canceled by averaging the test segments. A typical COSTAR plot is shown in Figure 6.

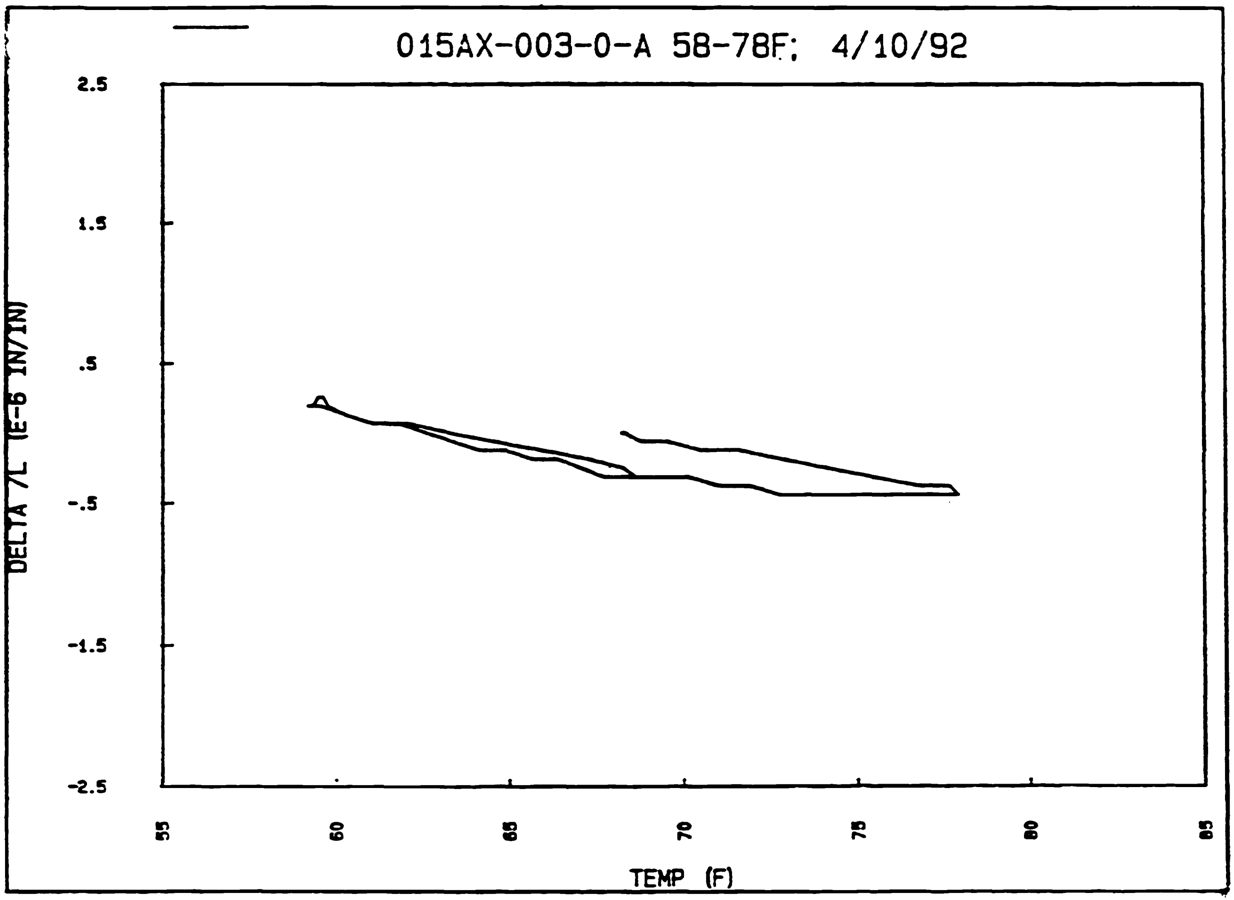

Figure 6 Typical Coupon Test Set Plot

3.0 FAST CTE TEST SET

The second test apparatus is quite different from the first. The Fast CTE Test Set simultaneously tests up to four coupons (see Figure 7). The goal is to perform multiple tests as fast as possible in atmosphere so the hygroscopic effect is not significant. The fast test time and accuracy is attributed to the use of LVDTs. The Fast CTE Test Set is patented under United States patent #4,923,307.

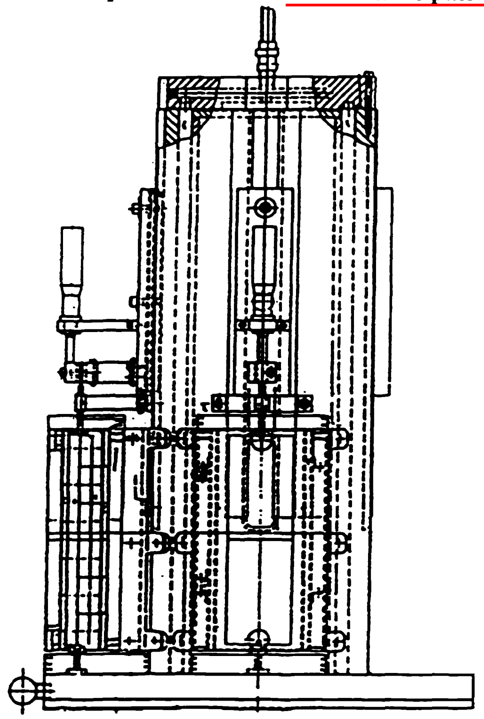

Figure 7 Fast CTE Test Set

The crux of the test set is the water-cooled support structure. The invar structure contains four test stations symmetrically oriented around the structure's center axis. Each coupon is held between two spherical-tipped Ultra Low Expansion (ULE™) glass posts which register in spherical seats ground into the coupon ends. Two precision thermistors are attached to each coupon to monitor the temperature with a 0.1 °F accuracy. The coupon temperature is changed via a heating and cooling shroud. The shroud is fabricated out of aluminum and is baffled to maximize heat exchange and temperature uniformity.

The measurement assembly for each quadrant is comprised of a LVDT coil and core (see Figure 8). Separate invar dual flexure systems suspend the core and coil from an invar dovetail slide assembly. The core is attached to the upper ULE™ post.

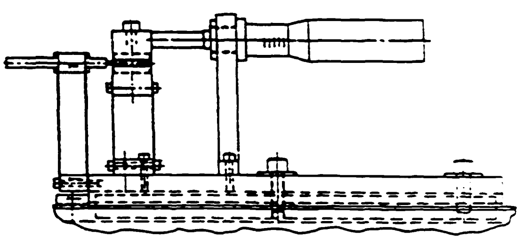

Figure 8 Fast CTE Test Set Measurement Assembly

The tests are performed in atmosphere between 60°F and 80°F. Again, a computer based data acquisition and control system is used to automatically perform tests and store data. Two cold-hot-cold temperature cycles are performed for each test to ensure accurate results. Isothermal conditions are required at each setpoint. The coupon is considered isothermal when for two minutes, the temperature remains within 3°F of the setpoint temperature, the two coupon thermistors are within 1°F of each other, the length does not change by more than 2E-6 inch, and the thermistor temperatures do not change by more than 0.5°F.

The CTE's for each segment are averaged to obtain the final coupon CTE. Typical COSTAR test data is shown in Figure 9.

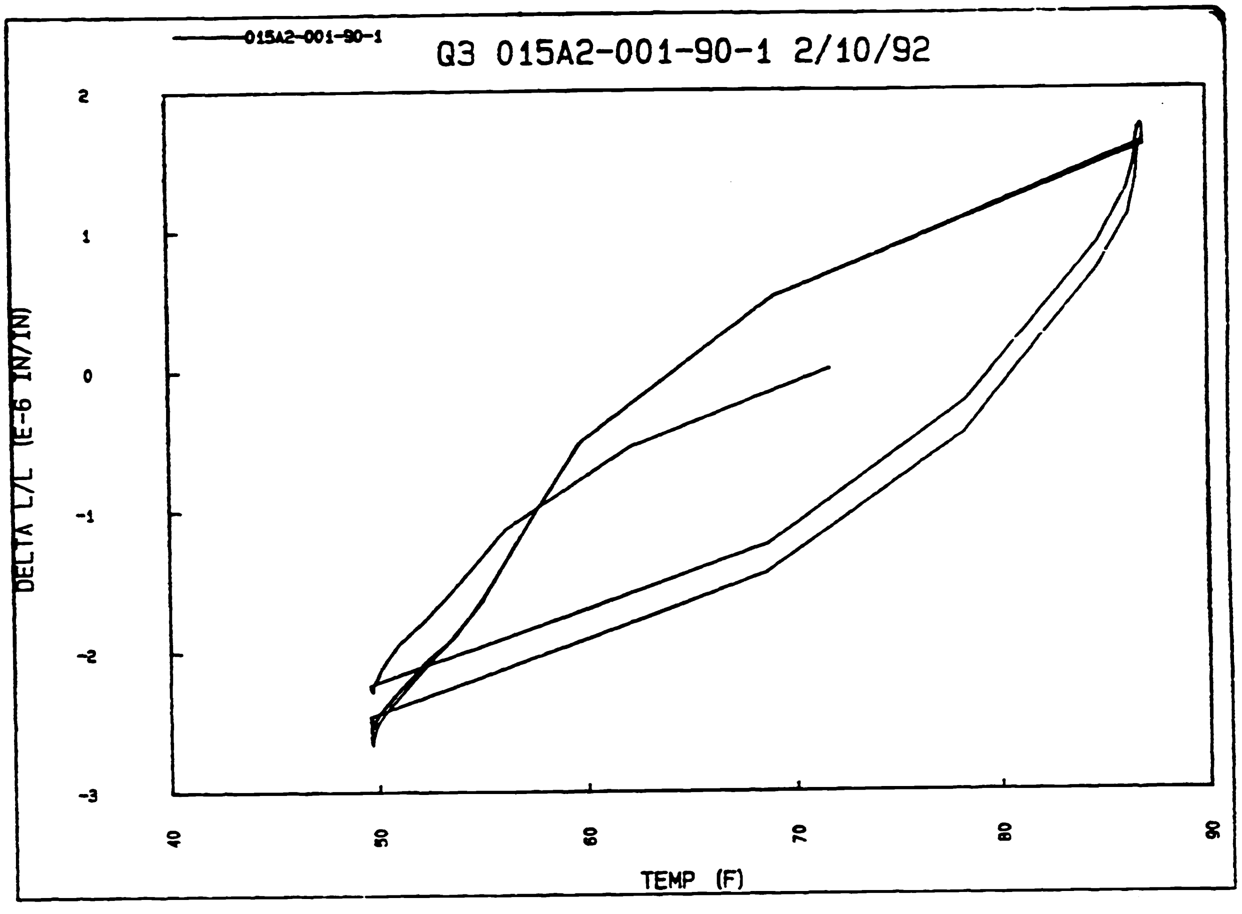

Figure 9 Typical Fast CTE Test Set Plot

4.0 UNIVERSAL TUBE TESTER

The third test set used to measure the CTE of tubes was the Universal Tube Tester. This test set is currently being kept as a trade secret. The essence of the test set will be described.

The means of measuring length change is the HP 5528A. A beam splitting interferometer is at one end of the tubular coupon and a retroreflector is at the other end. Unique sample mounts were designed that allow for easy and accurate backout determination.

Thermistors were used to measure coupon temperature. The thermistors were accurate to within 0.02°F.

The worst case error budget and the actual test errors are shown in Figure 10.

The main axial tubular elements of the Fixed Optical Bench were 80 inch long rhomboids. The CTE requirement was nominally zero. The four flight tubes were tested in this apparatus. Typical rhomboid data is shown in Figures 11-13.

5.0 SUMMARY

The COSTAR project had an aggressive schedule of precise measurements. The developmental test results were forwarded immediately to Hercules and Ball Aerospace. Real time decisions were made to alter the developmental test plan depending on previous test results. Layup angles and fiber volumes were determined and production began. The production schedule was also fast paced. Coupons were shipped overnight and results were telephoned in.

All the developmental and acceptance testing totaled 121 tests. Coupons ranged from 0.114 inch to 0.323 inch thick. The various cross sections were flat, square, triangular, and rhomboidal.

All of the described test sets at Eastman Kodak are traceable to the National Institute of Standards and Technology (NIST). The COSTAR coupons were often tested in multiple test sets to ensure accuracy. Eastman Kodak is able to perform round robin testing within its own lab between three unique test sets with NIST Standard Reference Material 739 (Fused Silica) and most any other coupon.

UNIVERSAL TUBE TESTER

COSTAR 80" Rhomboid
uncertainty budget:

contributor	wc error (E-6/F)	typical (E-6/F)
length (±0.05")	.00003	.00003
delta length (±2E-6")	.0008	.0004
delta temp (±0.9F)	.0014	.0008
laser noise (±30E-6")	.0121	.0000
backout (15E-6")	.006	.0004
Total Uncertainty	.020	.00163

Figure 10 Universal Tube Tester Error Budgets

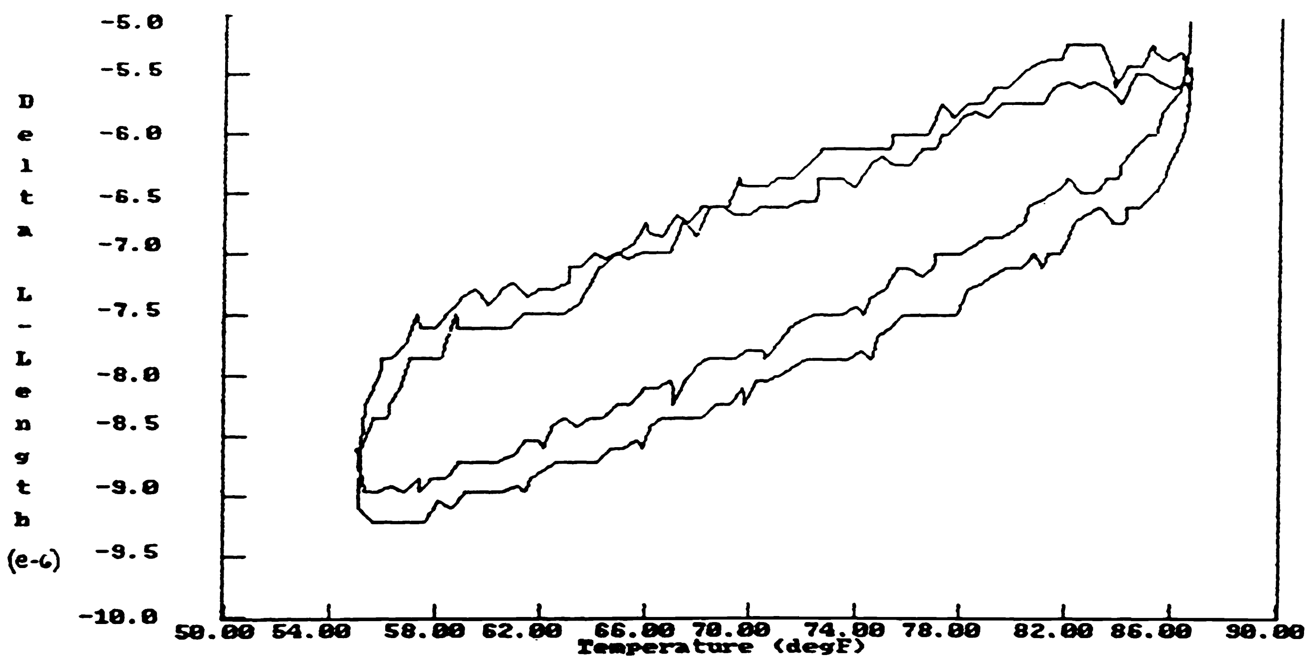

Figure 11 Typical Universal Tube Tester Plot

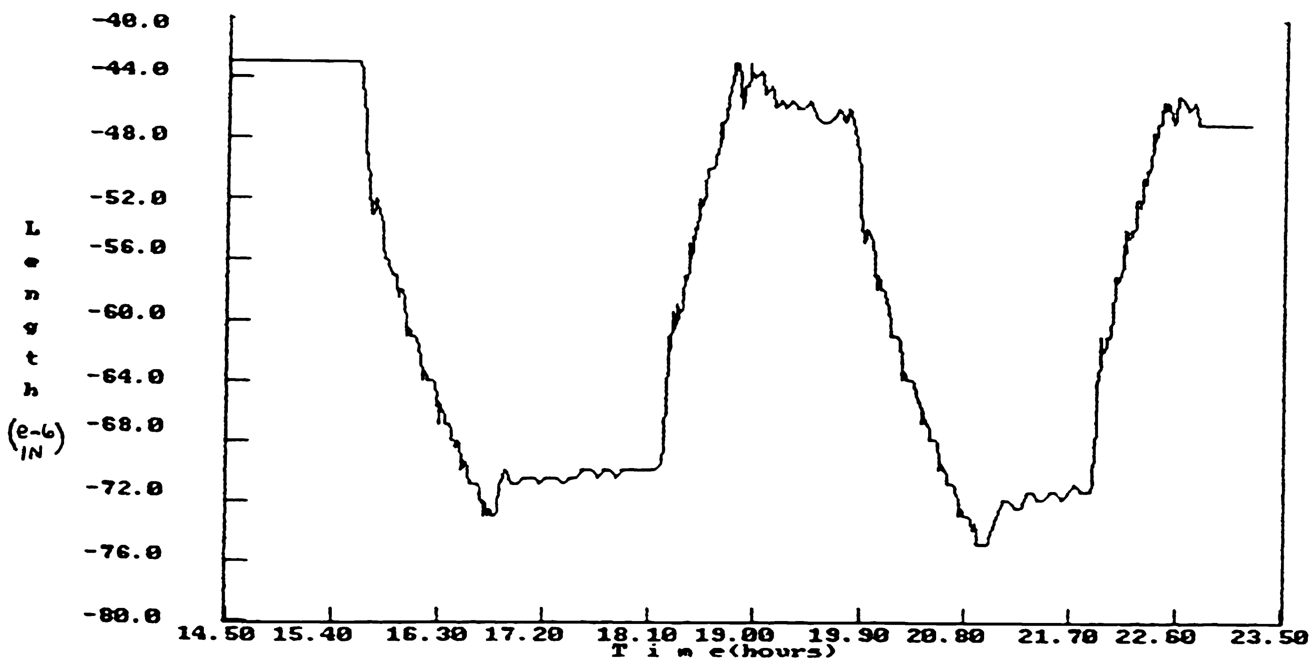

Figure 12 Typical Universal Tube Tester Plot

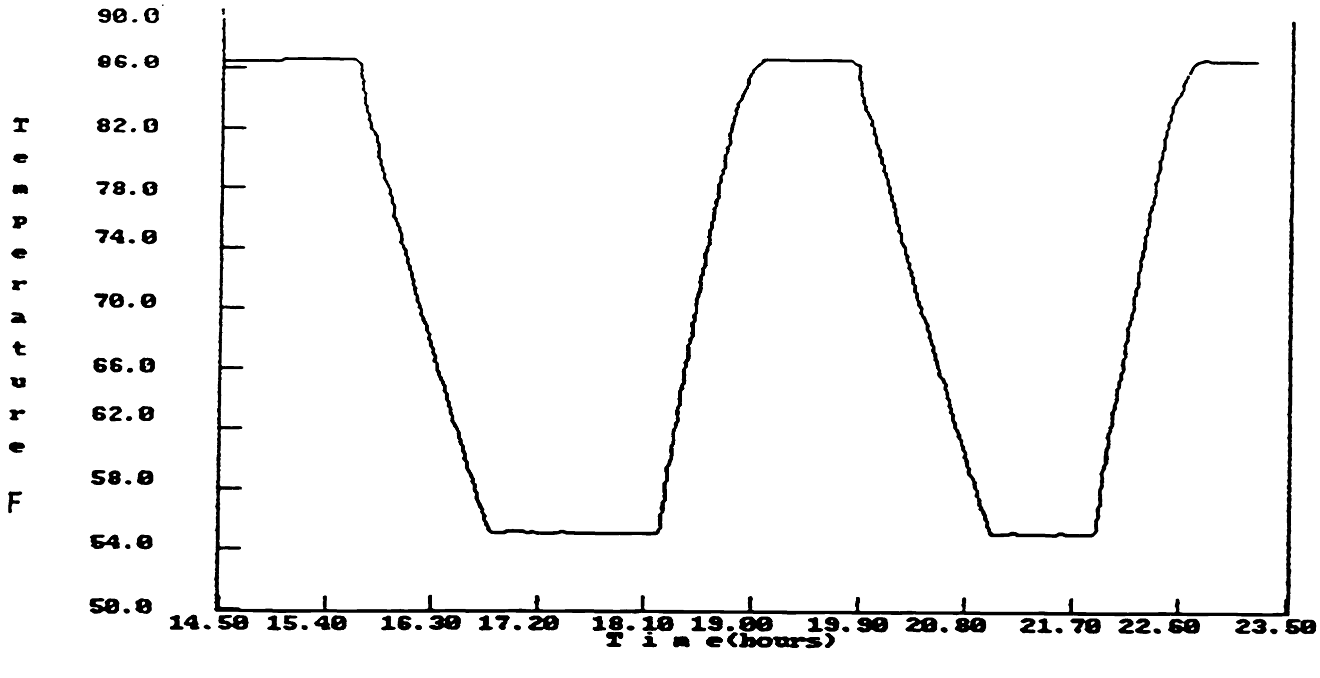

Figure 13 Typical Universal Tube Tester Plot