Raychem
Energy Division

Report

Title Analysis of Heat Aging Data on BBIT Material to Determine Pre-Aging Conditions for Nuclear Qualification Testing		Pages: 11 Enclosures:
Report Number: EDR-5063	Date: 11/19/82	
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CONTENTS

SUMMARY

An extensive study of the aging characteristics of the BBIT material used for BBIT heat shrinkable tubing for nuclear applications has been conducted. IEEE 383-1974 requires components to be pre-aged to a condition equivalent to their design life in the nuclear generating station as part of qualification testing. To fulfill these requirements, the aging characteristics of materials must be determined. This report outlines the heat aging test procedure to define these characteristics. It presents and analyzes the results using an Arrhenius plot and establishes the end-point criterion to determine the aging time-temperature relationships for BBIT material.

1.0 OBJECTIVE

The objective of this report is to present and analyze the Arrhenius data obtained during heat aging studies of Raychem BBIT material to determine pre-aging conditions for qualifying BBIT heat-shrinkable tubing to IEEE Standard 383-1974[1] and IEEE Standard 323-1974[2].

2.0 CONCLUSION

A time-temperature relationship, based on an Arrhenius plot, has been established for BBIT material which satisfies the requirements of IEEE 383-1974. This is presented graphically in Figure 2 and shows an Arrhenius line that extrapolates beyond 40 years at 90°C. It provides the basis for establishing accelerated pre-aging conditions for BBIT material before qualification testing.

3.0 INTRODUCTION

The requirements for electric cables and related materials such as splice insulating parts for nuclear power plants are given in IEEE 383-1974. This document states that type test for design basis event conditions should consist of subjecting non-aged and aged cables, field splices, and connections to a sequence of environmental extremes which simulate the most severe postulated conditions of a design basis event and specified conditions of installation.

The aging requirement is further explained in another section of IEEE 383-1974 which states that the basis for establishing time and temperature conditions for aging of samples to simulate their qualified life may be that of Arrhenius plotting or other method of proven validity and applicability for the materials in question.

It is generally specified that the design life of a nuclear generating station is 40 years and that the majority of the cables used in the plant are rated for a 90°C continuous conductor temperature. Actual conductor operating temperatures typically will be lower than 90°C. It is conservative to assess the aging performance of the BBIT material at the rated conductor temperature. To satisfy these requirements, the cables and splice systems should be aged to the equivalent of 40 years life at 90°C as part of the qualification testing required by the standards.

This report documents the times of oven exposure for die cut specimens and compares them to the resulting elongation remaining at the end of these exposures. Four oven temperatures were used between 125°C and 200°C. Elongation values are given as percent of the original value.

This data has been analyzed using a 40 percent retention of elongation as the end of life value. The resulting Arrhenius plot forms the basis for equating various time-temperature combinations during pre-aging exposure to their equivalent life.

4.0 TEST PROCEDURE

4.1 Specimen Preparation

Sample Preparation

Lengths of standard manufactured BBIT tubing were fully recovered in an oven at 150°C for 10 minutes. Upon removal from the oven the tubing samples were quickly slit longitudinally and flattened under a cold, heavy weight. From these flattened samples, dumbbell specimens were die cut[(1)] in the longitudinal direction.

From the total lot of dumbbell specimens, 10 specimens were picked randomly and tested in accordance with ISO 37-1977 for ultimate elongation. The ultimate elongation values obtained from these specimens were averaged and used as the original values to which the heat-aged samples were compared.

[1]ISO-37-1977, Type 2

4.2 Oven Aging

Four forced air type ovens were used for heat aging, set at 125°C, 150°C, 175°C or 200°C, respectively. The ovens were calibrated with a 12 channel recorder, utilizing 6 of the channels and positioned in 6 different zones of the oven. The temperature was monitored daily with a single thermocouple. The variation was less than 2°C of the set temperature.

The specimens, in groups of five, were hung vertically from the oven tray utilizing metal clips and hooks. The specimens were positioned such as to be no nearer than 2 inches to any inside wall of the oven chamber.

A group of five BBIT specimens was periodically removed from each of the ovens and the elongation measured at a crosshead speed of 4 inches per minute. The retention of elongation was plotted as a function of time at each exposure temperature. These are presented in Figure 1.
From these plots, the time corresponding to a specific retention of elongation could be determined. Table 1 lists times for several specifics. A list of data acquisition equipment and calibration information is given in Appendix A.

Just prior to the removal of specimens at 15,000 hours at 125°C, there was an oven failure, resulting in the oven overheating. The last available data point at 125°C was 11,000 hours. This time (11,000 hours) at temperature (125°C) gave ultimate elongation results of 225 percent which amounts to 42 percent of the original elongation.

5.0 ARRHENIUS PLOTTING

When the times to reach a selected end point at several temperatures are plotted on a graph with the logarithm of time as the ordinate and the reciprocal of the absolute temperature as the abscissa, it is said to be an Arrhenius plot. The IEEE standards do not state specifically what end point should be selected. Therefore, it becomes important to choose one that is consistent with the application. There are many possible parameters which can be used to select end point criteria, such as retention of elongation, retention of tensile strength, retention of dielectric strength, and voltage withstand tests after a mandrel bend test. It is also possible to select an end point not based on percent retention of the original properties but on a specific value of elongation or dielectric strength after aging.

Thirty percent retention of elongation was the desired end point, consistent with the criteria chosen for the other Raychem nuclear materials. (See EDR-5040 and 5046.) Due to the oven problem, this was not possible because either too much extrapolation would be required on the 125°C point, or it would have had to be deleted. Therefore, for the work described in this report a more conservative retention of 40 percent of the original elongation was chosen as the appropriate end of life criterion. Since the average ultimate elongation of this material in the unaged state was 534 percent, a retention of 40 percent would give an ultimate elongation of 214 percent at the end point. This is well in excess of the amount of elongation needed for any functional purpose. Some wire insulation in general use has less than this amount of elongation initially or as manufactured.

Regression analysis was applied to the values of the 40 percent column of Table 1. Using this regression line, times were recalculated for the temperature values and are detailed in Table 2. This regression line is presented in Figure 2.

6.0 DETERMINATION OF ACCELERATED AGING CONDITIONS

An extrapolation of the regression line indicates that the material will retain 40 percent of its initial elongation after 49 years at 90°C. Therefore, to determine appropriate accelerated aging conditions for the purpose of pre-aging specimens for DBE tests, a second line may be drawn which passes through any point corresponding to a desired time-temperature relation and is parallel to the regression line. This point must fall below the actual Arrhenius line. As an example, such a line is shown as Curve B of Figure 2 for the desired 40 years at 90°C point. Curve B will have the same heat of activation as the regression line. This heat of activation is 28.6 k Cal/mol. Now, any point along Curve B represents a time-temperature combination that may be used to age specimens to simulate pre-aging conditions for Qualification Testing. A few such conditions are given in Table 3.

7.0 TABLES AND GRAPHS

TABLE 1 Base Oven Aging Data for BBIT Material

Oven Temperature (°C)	Time (hrs.) to Various Levels of Retained Elongation		
	60%	50%	40%
125	4,640	6,660	12,800 (1)
150	750	1,060	1,540
175	158	213	252
200	31	35	40

TABLE 2 Time-Temperature Relationship of BBIT Material Using 40 Percent Retention of Elongation (regression analysis)

Temperature (°C)	Time (hrs.)
125	13,150
150	1,548
175	231
200	42

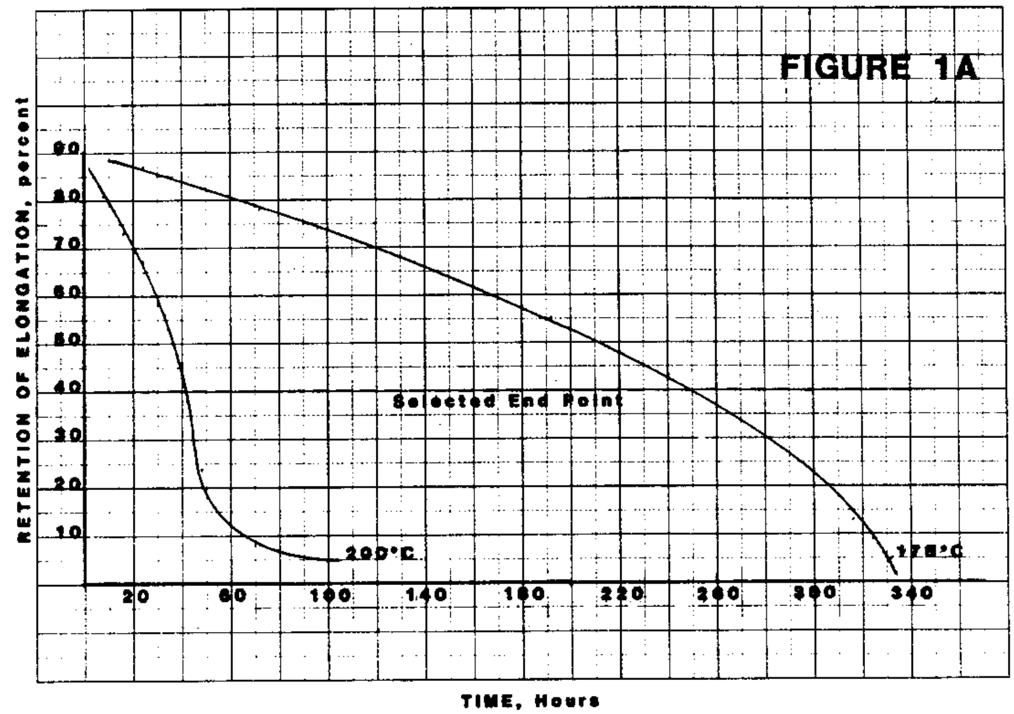
TABLE 3 Aging Times and Temperatures Needed to Satisfy a 40-Year Life at 90°C Requirement (Curve B)

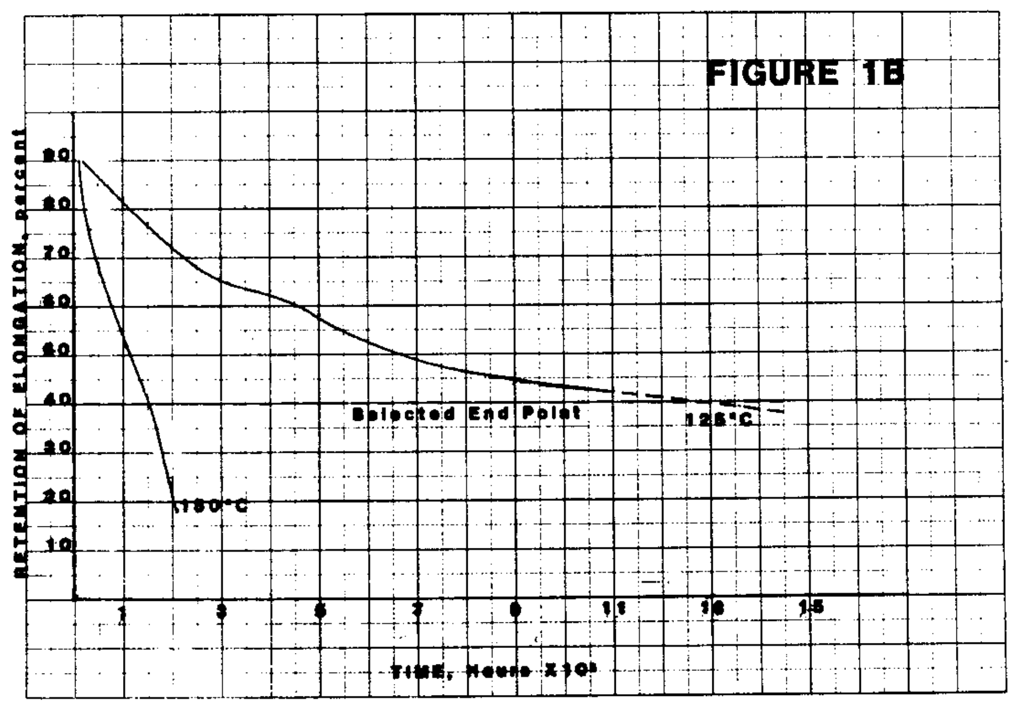
Temperature (°C)	Time (hrs.)
125	10,695
150	1,259
175	188
200	34

(1) 40 percent data point for 125°C extrapolated from 11,000 hour, 42 percent data point - indicated by dotted line on Figure 1B.

FIGURE 1

OVEN AGING DATA of BBIT MATERIAL





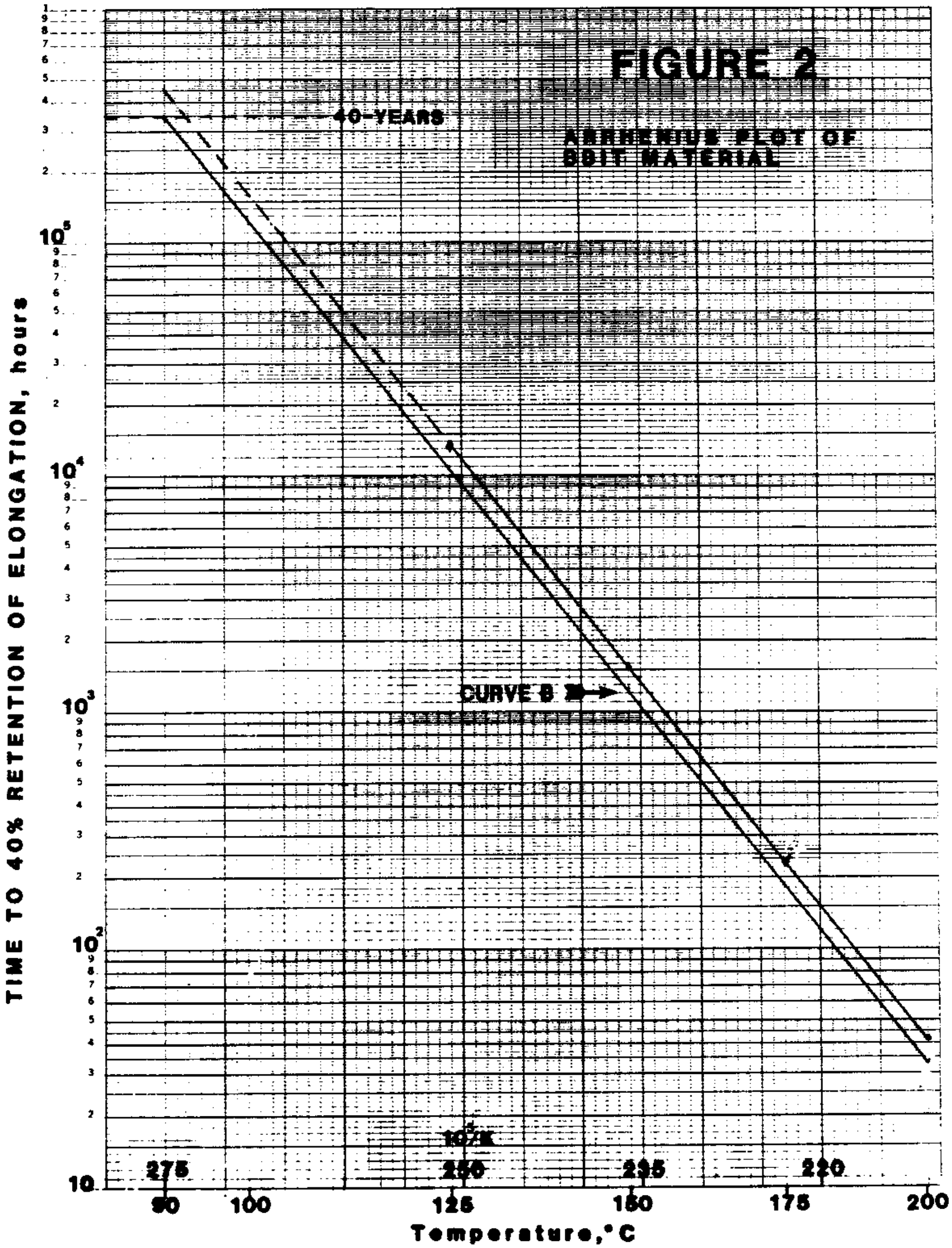


FIGURE 2
ARRHENIUS PLOT OF
SBIT MATERIAL
40-YEARS
CURVE B
TIME TO 40% RETENTION OF ELONGATION, hours
10
10^2
10^3
10^4
10^5
$10^3/K$
275
250
235
220
90
100
125
150
175
200
Temperature, °C

8.0 REFERENCES

(1) IEEE Standard 383-1974, "IEEE Standard for Type Test of Class Electric Cables, Field Splices, and Connections for Nuclear Power Generation Stations."

(2) IEEE Standard 323-1974, "IEEE Standard for Qualifying IE Equipment for Nuclear Power Generating Stations."

(3) Raychem Laboratory Notebook 001

(4) ISO-37-1977, Rubber Vulcanized Determination of Tensile Stress-Strain Properties.

(5) EDR-5040, "Analysis of Heat Aging Data on -52 Molding Material to Determine Pre-Aging Conditions for Nuclear Qualification Testing."

(6) EDR-5046, "Analysis of Heat Aging Data on WCSF Material to Determine Pre-Aging Conditions for Nuclear Qualification Testing."

9.0 APPENDIX A

LIST OF DATA ACQUISITION EQUIPMENT

Instrument	Mfg.	Serial No.	Model No.	Last Calibrated	Calibration Frequency	Range	Accuracy
Temperature Recorder	Digital	47860508	—	07/80	6 months	-190°C to +160°C	± 0.1°C
Temperature Recorder	Comark	13914	—	03/81	6 months	-200°C to +1300°C	± 1°C
Instron	Instron Ltd.	--	Type 1026	Before Use	Before Each Use	.0004"/min to 40"/min*	± 0.1%

* Separation Rate Range