Lifetime prediction and failure analysis based on accelerated life test of AWG module for optical communication

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1. Introduction

The accelerated life test is designed to accelerate the failure of a product by testing at stress levels in excess of its normal service parameters in order to analyze the failure data observed under accelerated conditions to extrapolate the estimated life-stress relation back to normal-use conditions to accurately estimate the service life of a product (1).

The AWG module, a key component of the DWDM transmission system to build a 5G network, is a component that requires a service life of at least 100,000 hours for stable transmission quality (2).

The purpose of this study is to estimate the service life of a 50GHz AWG module by conducting an accelerated life test.

2. Accelerated life test

2.1 Test Plan

The test was performed by accelerating stress by temperature to estimate the life-stress relation using the Arrhenius relationship, with 4:2:1 allocation ratio, to increase the accuracy of the service life estimates by considering the stress extrapolation and time extrapolation proposed by Meeker and Hahn (3)(4).

2.2 Preparation

As shown in Table 1, the samples were placed in 3 high-temperature chambers under 3 different high-temperature test conditions: 74℃, 86℃, and 100℃. In terms of measuring the characteristics, this study performed intermediate measurements for each hour for a total of 2,000 hours using an optical source, optical switch, and optical power meter, as shown in Figure 1. The failure criterion of the samples was based on accidental failure or a 50% change in the initial measurement.

Table 1 Test conditions

Items	Temperature (℃)	Samples (EA)
Chamber 1	74	12
Chamber 2	86	6
Chamber 3	100	3

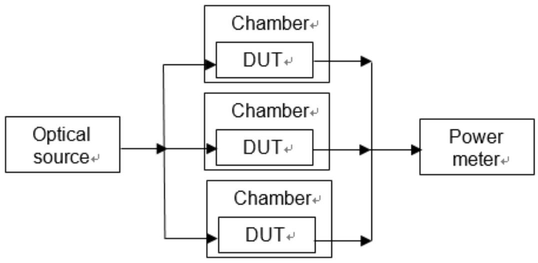

Fig. 1 Set up for accelerating aging test

3. Accelerated life test simulation

3.1 Accelerated life test model

As a result of comparing the likelihood function values of the exponential, lognormal, and Weibull distributions of the data collected for 2,000 hours for the accelerated life test, the lognormal distribution with the greatest likelihood function value was found to be the most suitable service life distribution.

The test temperature was set by estimating the Weibull distribution, but the lognormal distribution was found to be suitable.

Table 2. Conformance result of life distribution

Distribution	Exponential	Lognormal	Weibull
LK	-88.03	-86.26	-88.02

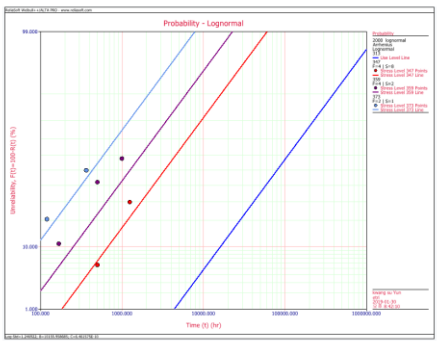

Fig. 2 Lognormal probability plot

Figure 2 shows the failure data observed during the accelerated life test using ALTA S/W. The data for each test condition is arranged close to a straight line and the line estimating the distribution of service life appears parallel, which indicates that lognormal distribution is suitable and that acceleration is formed between the test conditions.

3.2 Lognomal and life stress relationship

The life distribution model was based on lognormal distribution, and this study used the Arrhenius Relationship as the life-stress relation ship, which is widely used for accelerated life tests by temperature, as shown in Equation (1).

$$\zeta(T) = A \cdot \exp\,[E/(kT)] \qquad (1)$$

Where, ζ(T) is the life distribution parameter, E is the activation energy (eV), k is the Boltzmann constant (8.617 × 10^{-5} eV / °C.), T is the absolute temperature (K, °C + 273.15), and A is the constant according to the material properties and test conditions.
The acceleration factor (AF) from the life-stress relationship is shown in Equation (2) below.

$$AF = \zeta(T_d)/\zeta(T_a) = \exp[(E/k)\cdot(1/Td-1/Ta)] \qquad (2)$$

Where T_d is the life under the use conditions and T_a is the life under accelerated conditions. Since the activation factor (Ea) estimated from the software is 0.875, we can calculate the acceleration factor for each accelerated stress, and the life-stress relationship with respect to temperature in Figure 3 shows that the service life is reduced as the temperature increases.

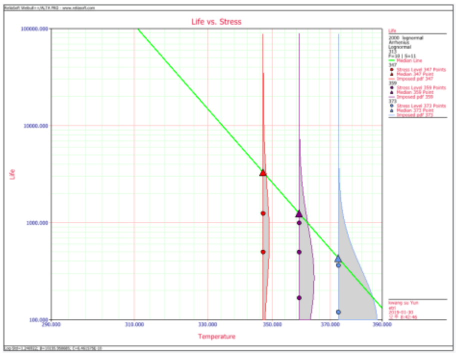

Fig.3 Life vs Stress

4. Test data

Table 2 summarizes the results of failure under each temperature condition for 2,000 hours during the accelerated life test.

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Table 3. Failure sample by temperature

Time \ Tem.	74℃	86℃	100℃
120 h	0	0	1
168 h	0	1	0
365 h	0	0	1
500 h	1	2	0
1000 h	0	1	0
1250 h	3	0	0
2000 h	0	0	0
Failure totals	4	4	2

5. Failure analysis

This study observed the changes in epoxy used for fixing parts after testing for a long period of time under high temperatures with a microscope and SEM photos, as shown in Figures 4 and 5.

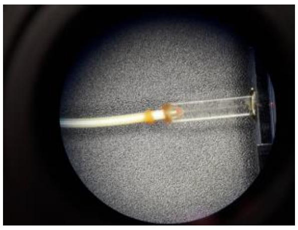

Fig. 4 86℃, 1,000 h, Fail(Microscope)

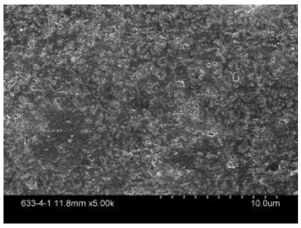

Fig. 5 100℃, 120 h, Fail (SEM 10㎛)

This study assumes that the deterioration of epoxy caused by high temperature resulted in deformation between parts, which influenced the increase of loss and ultimately resulted in failure.

6. Conclusion

The accelerated life test by high-temperature stress of the AWG module follows lognormal distribution, and the activation factor calculated by S/W is 0.875eV, and the deterioration of epoxy due to long-term high-temperature tests is one cause of failure (5).

The mean life was calculated to be Max. 1.736 x 10^5 (about 19.8 years) at 40℃ under normal-use conditions, which guarantees the service life of 10 years required for optical communication components.

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