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A Profile Analysis about Two Group Thermal Life Data

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Abstract. Since 1987, when statistical analyzing guide for thermal life test of accelerated life test (ALT) was proposed as ANSI/IEEE Std 101, this guide has been widely used for analysis of many different types of experimental data. Shim (2004) had done Monte Carlo simulation to compare life of two different systems or materials, based on statistic values obtained from ANSI/IEEE Std101 data. In this study, a profile analysis is proposed for comparing life of two different systems or materials: computers, smartphones, and so on, for example. Analysis examples using pre-existing data are also given.

Keywords: Arrhenius model, Accelerated life data, Electrical insulating materials, profile analysis, thermal life data

1 Introduction

Reliability is a possibility or an ability of a product to perform a certain function under a given condition for an intended period. To evaluate an accurate reliability, functions and environment required to products should be regulated. ALT (Accelerated Life Test), a method for detecting a product's life or fault rate, accelerates degradation cause both in the sense of time and physical aspects. The main purpose of ALT is to obtain the data of a product's life, and to statistically estimate life of the product when it is used.

If the life and stress is in linear relation, estimate parameters are needed to find out regression line. However, if there are some problems in the data, estimated parameters and confidence intervals can be affected seriously. Shim(2004) has proposed that for the data following log-normal life distribution or whose numbers are small, using simulation for estimating parameters and confidence intervals can be more accurate than using method proposed in ANSI/IEEE Std 101.

In this study, based on Shim(2004) and ANSI/IEEE Std 101, profile analysis is used to compare life of two different systems or materials for the case of small number of data following lognormal life distribution. For life-stress relation, Arrhenius Model is used, and data about life is created based on statistics from ANSI/IEEE Std. 101 data.

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2 Arrhenius Lognormal Model

The most general environmental stress for ALT on electronic device is temperature. Arrhenius Model is used when the product's life is a function of temperature. This equation shows the relation between temperature and life of an insulator.

$$K = S' \exp(-E/\theta T) \; . \tag{1}$$

K is Chemical reaction rate, E is an activation energy of the reaction which varies values with respect to failure mechanism, and its unit is eV(electron Volt). θ is Boltzmann Constant $\theta = 8.617 \times 10^{-5}\mathrm{eV}/°\mathrm{K}$, T is Kelvin Temperature $℃ + 273.16$, and S' is a constant which shows a product's characteristic or testing condition. Arrhenius Model is an application of Arrhenius Equation to ALT, and it assumes that when the reaction reaches the critical amount, fault occurs.

Therefore, which means that the critical value can be obtained as shown below,

Critical value = reaction rate × time to failure

and the time to failure t can be expressed like below.

$$t = \text{Critical value/reaction rate} = S \exp(E/\theta T)$$

By log transformation the model, median life of the insulator data becomes proportional to 1/t, and this relation is shown below.

$$\log(L) = \log(S) + (E/\theta T) \; . \tag{2}$$

Here, log is a common logarithm. Equation (2) can be expressed in algebraic form.

$$Y = A + BX \; . \tag{3}$$

In the equation, X=1/T, A=log(S), B=E/θ and Y is log(L) which can be expressed as a log linear equation showing nominal log life. In the equation (3), coefficients A and B can be estimated from the experiment data, and both a and b are sample estimators.

L_{ij} is sample j's life under temperature i, and if its log value is Y_{ij}, i=1,...,n, j=1,...,m, then Y_{ij}= log(L_{ij}), and under the arbitrary temperature i, the mean of Y_{ij} is $\overline{Y}_i$, and standard deviation is s_i.

3 An estimation between life and temperature

Let's apply Arrhenius Model to analyzing the thermal life data, and make several assumption to estimate the change of life with respect to temperature. Here are assumptions. ① The relation between log life and inverse Kelvin temperatures are linear relation in the temperature range we are interested in. ② Sample data are statistically independent. ③ Sample is selected arbitrarily from population which is under interest. ④ Random variation of log life follows a normal distribution which has equal standard deviations under every temperature of interest.

Following above assumptions, change each Celsius temperature T to inverse Kelvin temperatures like below.

$$X_i = 1/(T_i + 273), \quad i = 1, \cdots, n. \tag{4}$$

Since each failure life in sample L is converted to Y (Y=log(L)), sample estimator from population A, B in the equation (3) can be expressed as below.

$$a = \bar{Y} - b\bar{X}\ , \qquad b = \frac{\sum_{i=1}^{n} X_i Y_i - n\bar{X}\bar{Y}}{\sum_{i=1}^{n} X_i^2 - n\bar{X}^2}\ . \tag{5}$$

If $m(T_i)$ is the sample estimator of population mean log life from selected temperature T_i, the $m(T_i)$ can be calculated by using below equation.

$$m(T_i) = a + b[1/(T_i + 273)]\ . \tag{6}$$

The antilog of $m(T_i)$ is a median life estimated value for time unit under the temperature T_i. Here is a sample standard deviation of log life

$$s = \sqrt{\frac{1}{n-2}\sum_{i=1}^{n}(Y_i - (a + bX_i))^2}\ . \tag{7}$$

For the selected temperature T_i, following equation can be obtained.

$$V(T_i) = \frac{(X_i - \bar{X})^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2}\ . \tag{8}$$

Here, X_i is a inverse Kelvin temperature, $X_i = 1/(T_i + 273), \quad i = 1, \cdots, n.$
Confidence upper limit $m_U(T_i)$ and confidence lower limit $m_L(T_i)$ for mean log life $m(T_i)$ can be calculated as below by using equation (7) and (8).

$$m_U(T_i) = (a + bX_i) + t_{n-2}(\alpha)s\sqrt{(1/n) + V(T_i)}\ . \tag{9}$$

$$m_L(T_i) = (a + bX_i) - t_{n-2}(\alpha)s\sqrt{(1/n) + V(T_i)}\ . \tag{20}$$

4 Profile analysis of two group data

For an Electrical insulating materials, thermal resistance is one of the most important properties. They can be classified to 7 groups by the upper limit of temperature, and all 7 groups of insulator are composed of different materials.
Therefore, if there is some difference in mean log life between two equal kind of insulators, or there is little difference between two different insulator, they are possibly bad one.

To compare the life of two different kinds of systems or materials, thermal life test can be applied. After the data about both insulating materials are obtained, whether one material is clearly better or not can be observed by using Arrhenius line. Observed differences can be originated from an unexpected change. To assess if there is any reasonable difference, two sets of data should be compared, and this is similar to the method of comparing two means.

Comparison between lines can be done under more than one temperatures, and sometimes, comparison under a certain range of temperature can be more useful.

Profile Analysis is an analyzing method, examining whether the effect is equal or not when p processes(test, question, etc.) are done for more than two groups. It is similar to analysis of variance in the circumstance of agreement analysis of average vectors, but the difference is that profile Analysis includes several steps.

IF $\mu_1^T = [\mu_{11}, \mu_{12}, \cdots, \mu_{1p}]$ and $\mu_2^T = [\mu_{21}, \mu_{22}, \cdots, \mu_{2p}]$ are mean log life of response value for two population, null hypothesis $H_0 : \mu_1 = \mu_2$ can be reconstituted shown below.

Let $\bar{x}_1, \bar{x}_2$ are sample mean vector of two samples with size n_1 and n_2, and independent to each other. C is the contrast matrix. For testing whether two population's profile are parallel to each other, null hypothesis can be written below.

$$H_0 : C\mu_1 = C\mu_2 \ . \tag{31}$$

This null hypothesis can be examined by modified observations $Cx_{1i}, i = 1, \cdots, n_1$ and $Cx_{2j}, j = 1, \cdots, n_2$. Sample mean vector of modified observations are $C\bar{x}_1 = C\bar{x}_2$ each, and pooled sample covariance matrix is $CS_{pooled}C^T$. Therefore, null hypothesis (11) is reject when below conditions are satisfied.

$$T^2 = (\bar{x}_1 - \bar{x}_2)^T C^T \left[\left(\frac{1}{n_1} + \frac{1}{n_2}\right) CS_{pooled} C^T\right]^{-1} C(\bar{x}_1 - \bar{x}_2) > c^2 \ . \tag{42}$$

and,

$$c^2 = \frac{(n_1+n_2-2)(p-1)}{n_1+n_2-p} F_{p-1, n_1+n_2-p\,(\alpha)}.$$

5 Conclusions

A profile analysis with which we can perform life tests is proposed in this paper. Performing life tests in the early stage of computer system design is very important.

Therefore, the proposed method will contribute to save the cost of system design. For the further research, we are applying the method on practical applications.

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References

1. Kyubark Shim, Simulation about thermal life test data of two different insulating materials, Journal of the Korean Data Analysis Society, Vol.6 No.2, pp.603-611 (2004)
2. KINS/HR 551-2003, A Study of Instrument Verification Suitability about Digital Measuring Control System (2003)
3. ANSI/IEEE Std 101-1987, "IEEE Guide for the Statistical Analysis of Thermal Life Test Data", (1987)
4. James R. Evans, David L. Olson, Introduction to Simulation and Risk Analysis, Prentice Hall, New Jersey (2002)
5. Richard A. Johnson, Dean W. Wichern, Applied Multivariate Statistical Analysis 6th Ed., Pearson Prentice Hall, New Jersey (2007)
6. Oliver Thas, Comparing Distributions, Springer, New York (2010)