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Life time comparison of LED package and the self-ballasted LED lamps by simple linear regression analysis

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ABSTRACT

The energy efficient long-life self-ballasted LED lamps are designed considering the reliability test result of LED package. We also try to predict the lumen maintenance life for the self-ballasted LED lamps because there were a lot of failure mechanisms for a various environment stress. Many studies have investigated the environmental stress effects on LED packages [2,3,4, and 5]. However, comparing to LED package, there is not enough data to study the lumen maintenance life for the self-ballasted LED lamps. IES LM-80-08 is the approved method for measuring lumen maintenance of LED light sources [1]. It suggests using the Arrhenius Equation to calculate the interpolated lumen maintenance life. We followed this method and obtained lumen degradation patterns from three different thermal stresses as indicated in the IEC 62621 standard. Under the three different thermal stresses, the on-off test (30 on and 30 s off) was conducted on the self-ballasted LED lamps which were made of the same selected LED package (3 V, 64 mA). The intent of the research isn't to set up a new curve-fit for non-linear lumen degradation pattern. Our research goals are to find methods to compare the lumen degradation pattern of LED package and the self-ballasted LED lamp using simple linear regression analysis. As simple straight linear line is assumed for lumen degradation after ALT testing We found the slope of the mathematical model is easily comparable for three different temperatures and for different number of LED whether it is single or consists of forty or eighty LED. By comparing each values of the slope the effect of increase in number of LED can be shown at each thermal stress. This study is the first step towards the presentation on the lumen maintenance life of the self-ballasted LED lamp on three different temperatures. Additional information must be accumulated in the future to further study on the LED lighting product reliability.

1. Introduction

After the development of blue LED package in 1994 and the commercialization of white LED package, the lighting industry became more environmentally friendly with longer lifetime products. In Korea, the safety certification standards have been steadily established from 2009 with current 37 standards by various product types. However, there have been concerns on the method for evaluating the reliability of the LED package and also of the self-ballasted LED lamps which includes the power source. This paper will discuss the accelerated factors which were driven by many preceding studies and integrate the accelerated factors (temperature and electric stress) which have the biggest effects on the self-ballasted LED lamps lumen degradation. First, to verify the influence of temperature on the degradation of the self-ballasted LED lamps, accelerated stress tests at several temperature levels were performed. The lumen degradation test at the normal temperature condition was also performed to compare its result to that obtained at the accelerated conditions. Before we discuss the accelerated conditions, we first need a lumen degradation data of single LED package's temperature for long term test. Normal life test (25 °C) and thermal accelerated life test (70 °C, 90 °C) were first conducted on the low power LED package (3 V, 64 mA). Then the normal temperature (25 °C) plus 30 s on and 30 s off test and thermal accelerated life test plus 30 s on and 30 s off test were conducted on the self-ballasted LED lamps (8 W, 16 W) made with the same low power LED (3 V, 63 mA) installed on the Metal PCB. Input power was from 100 to 240 V of working Voltage and total lumen flux was 480 lm. Fig. 1 shows the test sample of a single LED package and the self-ballasted LED lamps (8 W, 16 W). In IEC 62621 (Self-ballasted LED Lamps for general Lighting services with supply voltages > 50 V — Performance requirements) the criteria of failure is below the minimum 70% of the initial lumen. In this research this criteria is used as a base for determining the failure data using Weibull analysis. Chan et al. recommended LED's activation energy to be 0.33 eV when using Weibull analysis [5]. Therefore, we adopted this Weibull analysis for HAST testing results. The total test condition for the research are designed following the below Table 1. The normal life

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Fig. 1. Test sample (Single LED, Self-ballasted LED Lamps (8 W-42 LED, 16 W-88 LED)).

Table 1
Test condition.

LED num.	Test condition		Sample	Testing time
1 ea	25 °C		25	10,000 h
1 ea	70 °C		10	7200 h
1 ea	90 °C		10	7200 h
8 W(42 ea)	25 °C	30 on/off	5	9100 h
8 W(42 ea)	80 °C	30 on/off	5	8000 h
8 W(42 ea)	90 °C	30 on/off	5	5500 h
16 W(84 ea)	25 °C	30 on/off	5	4400 h
16 W(84 ea)	70 °C	30 on/off	5	4400 h

test have been conducted following the test condition with temperature of 25 °C, tolerance of ± 1 °C and a relative humidity of 65% maximum as indicated in IEC 62612 for minimum of 4000 h to maximum of 10,000 h (one and a half year).

2. Experiment 1 (Single LED Life Testing)

Yoon et al. mentioned that Korean products of low power LED (30 mA, under 1 W) which contain the commercialized YAG type phosphor have the values of the shape parameter between 11 and 14 [4] at 25 °C, 70 °C and 90 °C when using Weibull analysis. So we chose a similar YAG type LED which the K-factor was 1.24–1.28 mV/ °C and thermal resistance was 32.62–33.97 °C/W. Fig. 2 shows the lumen degradation pattern obtained from normal life test with temperature at 25 °C, 70 °C and 90 °C. The graph shows the mean value of 25 samples for normal life test (25 °C) and the mean value of 10 samples for 70 °C and 90 °C accelerated life testing. No large difference is shown between 25 °C and 70 °C at 2000 h. But over 2000 h, we can recognize the difference between 25 °C and 70 °C. So we were interested in having a quantitative comparison for three different temperature testing. Fig. 3

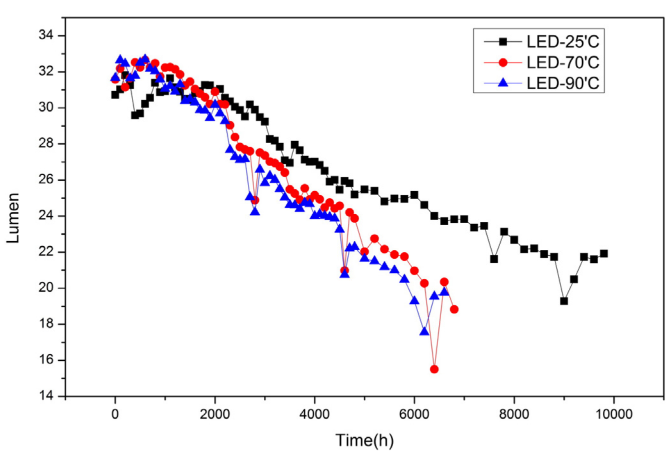

Fig. 2. Lumen degradation after thermal stress.

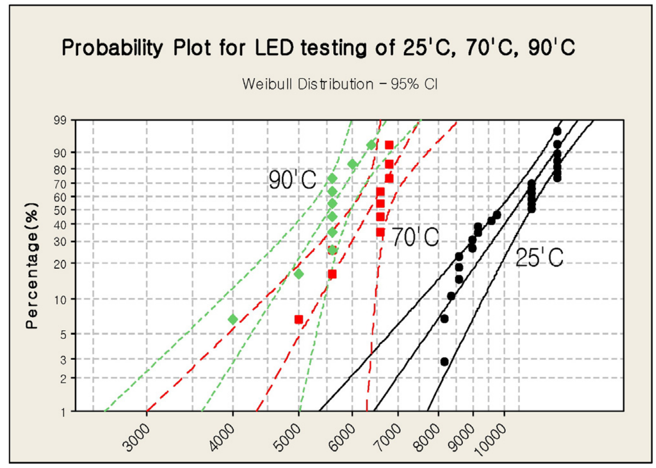

Fig. 3. Weibull plot of accelerated life testing.

shows the Weibull plot of degradation failure using L_{70} as a basis. Table 2 shows the scale and shape parameters of Weibell distribution estimated via maximum likelihood estimation (MLE). The test samples are in the wear out failure state as the shape parameter numbers 8.87, 11.12 and 9.85 are all above 3. It might be thought that LED under three temperature conditions failed from the same failure mechanism [4]. Fig. 4 shows the I–V curve and thermal resistance's changes at 7200 h after thermal stress testing. This indicates that the decrease of lighting power is in correlation with the change of chip's capacity and increase of thermal resistance.

Exponential least squares curve-fit for Eq. (1) is mentioned in IES LM-80-08 [1]. The decay rate constant in the equation is derived by using the least squares curve-fit method. After acceleration life test, all samples had a decay rate constant. As the equation is simple, comparison can be easily made for all results (Fig. 10). And hence, the straight linear line was chosen instead of a new curve-fit equation. By using simple linear regression analysis, parameters for the least square estimation model can be deducted from Fig. 5 [5]. Fitted regression line equation is shown as the following Eq. (1)

$$\hat{y}_l = b_0 + b_1 x_i \tag{1}$$

where:

$$b_0 = \bar{y} - b_1\bar{x}, \quad b_1 = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2}), \qquad R^2 = \frac{\sum\left(\hat{Y}_l-\bar{Y}\right)^2}{\sum\left(Y_i-\bar{Y}\right)^2} \tag{2}$$

where: i = 1, 2, ……, n.

The closer the value of R^2 (the square of multiple correlation coefficient) is to 100% the closer the model tends to follow the data [6]. The value of R^2 was near 96% for all 3 test conditions. This is an acceptable value. For example in Table 3, b_1 is 0.001251 in 25 °C and 0.002079 in 70 °C. The decay rate constant b_1 increased by almost two times while the scale parameter decreased by half when Weibull analysis was used.

Table 2
Test condition and shape parameters.

Temp.	Sample size	Failure	Shape para.	Scale para.
25 °C	25	25	8.87	10,804.4
70 °C	10	10	11.12	6569.5
90 °C	10	10	9.85	5761.1

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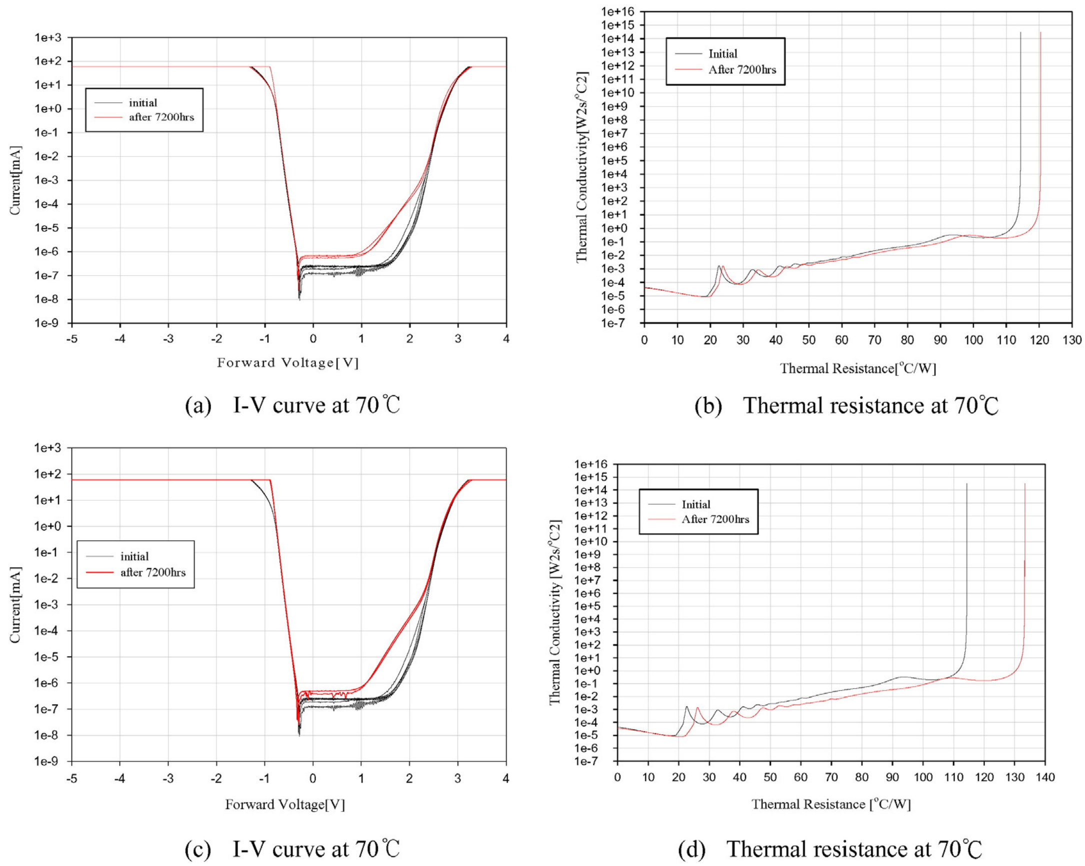

Fig. 4. I–V curve and thermal resistance at 7200 h after thermal stress (70 °C and 90 °C). (a) I–V curve at 70 °C. (b) Thermal resistance at 70 °C. (c) I–V curve at 70 °C. (d) Thermal resistance at 70 °C.

3. Experiment 2 (LED Lamp Life Testing)

The test samples used for normal life test and thermal accelerated life test were 8 W (Operating Voltage 110 V–240 V, 50–60 Hz, 484 lm, 5203 K) and 16 W (Operating Voltage 110 V–280 V, 50–60 Hz, 989 lm, 5547 K) self-ballasted LED lamps of same LED package model (3 V, 63 mA). The biggest problem of this product is consumer's claims due to poor lighting. As to resolve this problem we analyzed the defected product and causing the problem for less than 1 year. The part with highest claim's defect factors had 13 cases of power source defect and 4 cases of cap and base defect. Power source defect includes poor soldering and fuse breakdown caused by static electricity. These constitute 90% of early failures. This paper does not consider about infant mortality and random failures. Only wear-out failures will be discussed. Fig. 6 is the lumen degradation graph showing the result of 8 W normal temperature plus 30 s on and off test, 80 °C plus 30 s on and off test and 90 °C plus 30 s on and off test. Unlike the lumen degradation graph which the decay rate constant b_1 shows no difference between the 70 °C and 90 °C test condition in Table 4, the decay rate constant b_1 for the 8 W LED increased by two times from 80 °C to 90 °C. By the result it can be concluded that the life time degrades more rapidly as the number of LED increase. In Fig. 7, the shape

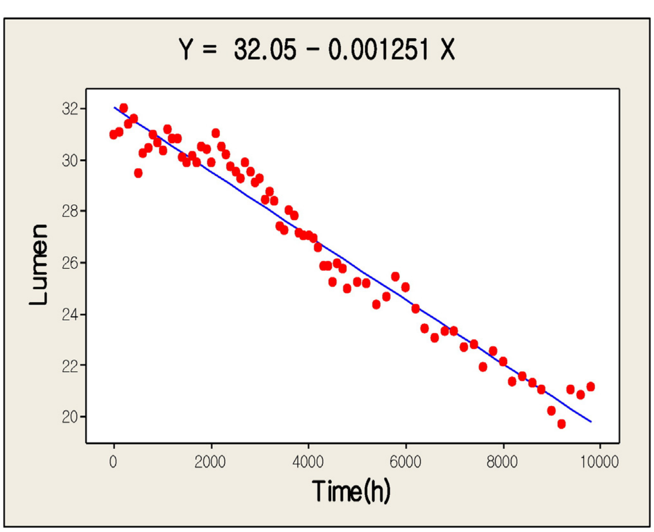

Fig. 5. Fitting a straight line by least squares.

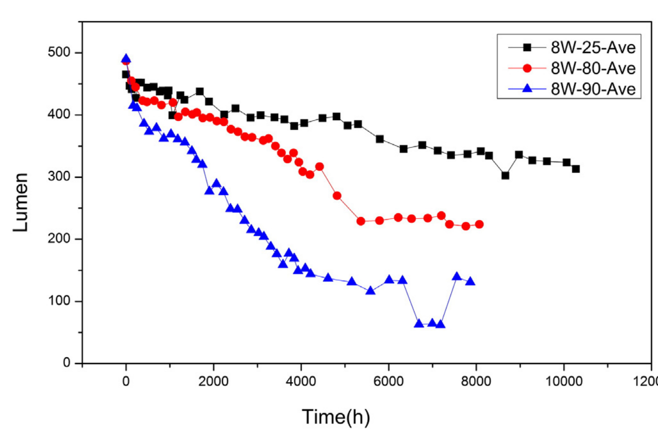

Fig. 6. Lumen degradation of 8 W LED Lamp after testing.

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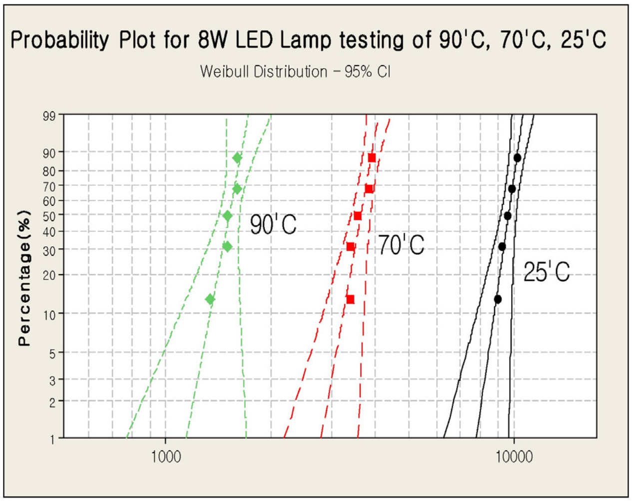

Fig. 7. Weibull plot of degradation failure.

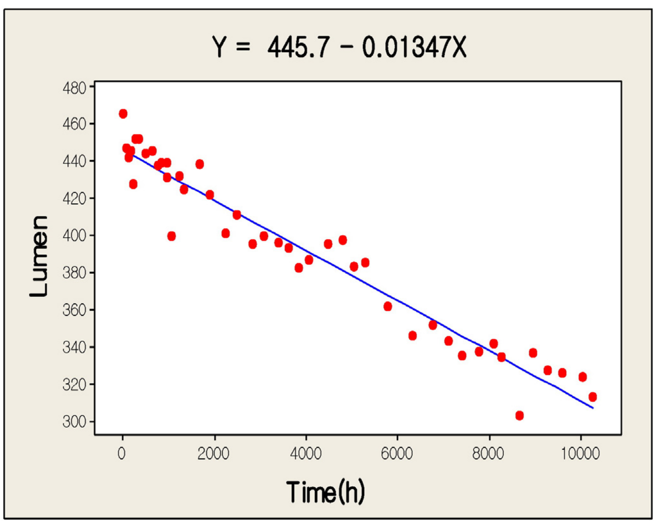

Fig. 8. Fitting a straight line by least squares.

parameters show a wear out failure mode and when we are comparing for a fitting line at 3 different temperatures, the acceleration is established. As shown in the regression analysis graph shown in Fig. 8,

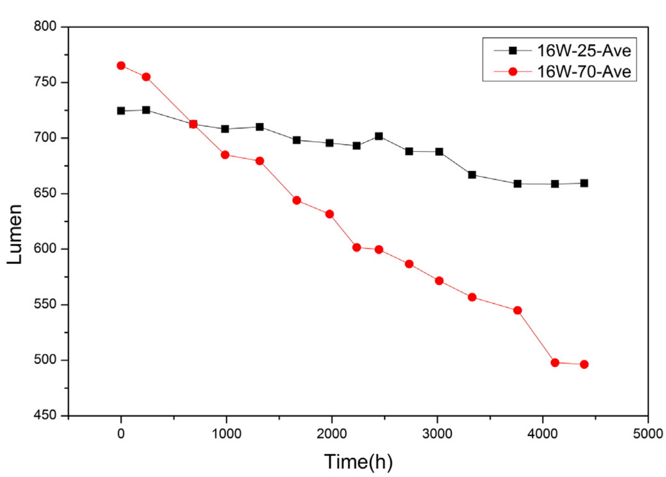

Fig. 9. Lumen degradation of 16 W LED Lamp after testing.

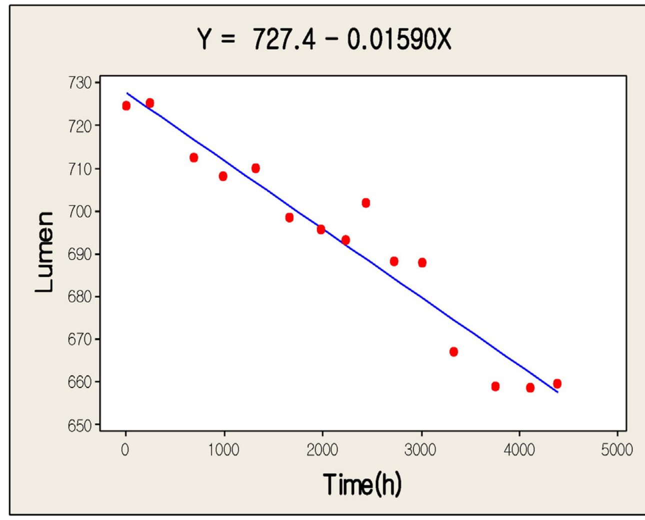

Fig. 10. Fitting a straight line by least squares.

the decay rate constant b_1 differs largely as the temperature increase. The conclusion made can be proved with the lumen degradation graph of 16 W which shows a larger difference in b_1 than 8 W. The result from the 70 °C test condition shows that the 16 W lumen degradation curve decrease more rapidly than the 8 W curve. The decay rate constant b_1 of 16 W under 70 °C test condition is shown in Fig. 9 and Table 6 and is shown to be similar to b_1 of 8 W under 90 °C in Table 5. The increase in number of LED is proved to effect the life time of the LED Lamp just as the result from thermal accelerated life test.

4. Conclusion

In Table 7, the parameter estimates of lumen degradation curve obtained from normal life test and thermal accelerated life test are listed. Using the decay rate constant b_1 from the LED normal life test as a base value, interesting result can be deducted showing the effect of

Table 3
Estimates of parameters.

Test condition	$\hat{y}_l = b_0 + b_1 x_i$	
	$-b_1$	b_0
25 °C	0.001251	32.05
70 °C	0.002079	32.51
90 °C	0.001988	33.1

Table 4
Test condition and shape parameters.

Temp.	Sample size	Failure	Shape para.	Scale para.
25 °C	5	5	19.8243	9834.59
80 °C	5	5	16.1309	3716.06
90 °C	5	5	14.8769	1557.58

Table 5
Estimates of parameters.

Test condition	$\hat{y}_l = b_0 + b_1 x_i$	
	$-b_1$	b_0
25 °C	0.01347	445.7
80 °C	0.03217	441.4
90 °C	0.06441	425.6

Table 6
Estimates of parameters.

Test condition	$\hat{y}_l = b_0 + b_1 x_i$	
	$-b_1$	b_0
25 °C	0.0159	727.4
70 °C	0.06081	755.3

Table 7
Estimates of parameters.

LED	Test condition	$\hat{y}_i = b_0 + b_1 x_i$		Ratio
		$-b_1$	b_0	
1 ea	25 °C	0.001251	32.05	1
1 ea	70 °C	0.002079	32.51	1.7
1 ea	90 °C	0.001988	33.1	1.6
42 ea	8 W-25 °C (on-off)	0.01347	445.7	10.8
42 ea	8 W-70 °C (on-off)	0.03217	441.4	25.7
42 ea	8 W-90 °C (on-off)	0.06441	425.6	51.5
88 ea	16 W-25 °C (on-off)	0.0159	727.4	12.7
88 ea	16 W-70 °C (on-off)	0.06081	755.3	48.6

temperature increase, number of increase in LED and 30 s on-off testing. First, the effect of temperature on LED was less than double but when the number of LED increased the effect of temperature increased from 3 to 6 times. This indicated that the slope of straight linear line will be steep and it means that the self-ballasted LED lamp will shorten in life time. By analyzing the data, the importance of thermal stress can be emphasized when designing the self-ballasted LED Lamp. Depending on the number of LED and the elimination of the thermal stress the life time of the LED can be significantly different under the same temperature condition. The paper can be considered as an initial step for comparing single LED with LED products using the decay rate constant b1. In the future, studies on not only the temperature but also the other environment stress factors are to be conducted.

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