Results on accelerated ageing characteristics for the selected SSL products

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Abstract	:	This report presents the 2-month periodic measurement results of 2 batches of LED lamps aged respectively at 2 elevated temperature of 45°C and 60°, during 6 months at LNE. The measured characteristics are the luminous flux, the spectral power density and the power consumption. A set of extra lamps was altered in order to probe the current and was aged as well at 45°C. All the results are provided with the help of tables and graphs and major results are compared to those of lamps naturally aged at MIKES. We derived two acceleration factors respectively for the two accelerated ageing tests.
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SUMMARY

This report presents the results of two accelerated ageing experiments conducted in a climatic chamber on a set of LED lamps at LNE. Two batches of lamps were aged respectively at two elevated temperatures of 45°C and 60°C, during 6 months. Each batch comprises 3 samples of 5 lamp types. The 2-month periodic measurement results of 2 batches of LED lamps, including initial and final measurements are presented for optical characteristics and electrical characteristics. We first present the measured optical characteristics which are the luminous flux and the spectral power density. The colorimetric parameters, Correlated Colour Temperature (CCT) and CIE 1931 chromaticity coordinates (x,y), are derived from the spectra. The major results, i.e. the luminous flux evolutions, are compared with the luminous flux evolutions of a set of same lamp types naturally aged at MIKES. We derived two acceleration factors for the two accelerated ageing tests at the temperature of 45°C and 60°C. Then we present the measured electrical characteristics which are the power consumption and the current delivered to the PCB supporting the LEDs. Five extra lamps, one sample per lamp type, were somewhat altered, but keeping the original lamp body and bulb, in order to probe the current along the first ageing test at 45°C. All the results are exposed with the help of tables and graphs to better visualize the characteristics evolutions against the accumulated operation time.

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LIST OF SYMBOLS

X	<Definition>

LIST OF ABBREVIATIONS

EMRP	European Metrology Research Programme
NMI	National Measurement Institute
JRP	Joint Research Project
SSL	Solid State Lighting
LED	Light Emitting Device
CCT	Colour Correlated Temperature
SPD	Spectral Power Density
PCB	Printed Circuit Board

1. Introduction

Two accelerated ageing experiments have been conducted at LNE using thermal stress at two different elevated temperatures while a natural ageing experiment has been conducted at MIKES. Choice and methods are fully explained and described in the deliverable D246, as well as the characteristics of the used facilities.

2. Measurement results

This report presents the periodical measurement results of optical and electrical characteristics of two sets of LED lamps subjected to accelerated ageing by thermal stress at two elevated temperatures of 45°C and 60°C. The main results are compared to the results of natural ageing performed at MIKES.

A comparison of optical and electrical characteristic measurements has been performed between LNE and MIKES. A good agreement was found on the initial measurements of lamps sent to LNE and then allows valuable results comparison of natural ageing conducted at MIKES and accelerated ageing conducted at LNE.

2.1. Measurement protocol

LNE was provided with 7 samples of 5 different references of lamps. A first batch of 3x5 lamps was dedicated to the first accelerated ageing experiment and a second batch of 3x5 lamps was dedicated to the second accelerated ageing experiment. The left sample of each reference was dedicated to electrical current measurement on modified lamps for the first accelerated ageing experiment..

For one accelerated experiment, consisting of thermal stress at elevated temperature, the following steps have been applied on the 5x3 lamps:

1. initial burning : 100 h – first optical/electrical measurements performed at MIKES,
2. initial optical/electrical measurements at LNE,
3. cycle : 2 months of ageing in a climatic chamber : ambient temperature 45°C or 60°C ,
4. periodic flux and PCB current measurement (*) – stabilisation time 2 hours,
5. back to step 3 until the lamps are aged by 6 months.
6. final electrical measurement

(*) PCB current measurements were performed only for the first batch.

No specific care was taken to handle the lamps and switch on/off the lamps. At each beginning of cycle the lamps power is turned on with the lamps in the climatic chamber set at room temperature. At each cycle end the lamps power is turned off in the climatic chamber at the elevated temperature and then the lamps extracted from the climatic chamber The lamps are handled with clean wool gloves to avoid optical contamination and thermal effect.

2.2. Lamps identification and initial characteristics

brand & reference	first batch ageing at 45°C	second batch ageing at 60°	extra lamps ageing 45°+60° current measurement
Philips Master LED	A2, A4, A6	A8, A10, A13	AX
Osram Parathom Par16 20	B2, B4, B6	B8, B10, B12	B17
Osram Parathom Classic A 40	C2, C4, C6	C8, C10, C12	CX
Osram Parathom Pro Classic A 80	D2, D4, D6	D8, D10, D12	DX
Osram Parathom Pro Classic A 60	E2, E4, E6	E8, E10, E12	EX

Table 1: Lamps identification

Lamp ID	Flux (lumen)	Power (W)	Lamp ID	Flux (lumen)	Power((W)
A2	807.8	12.6	A8	801.1	12.4
A4	796.9	12.5	A10	833.0	12.7
A6	805.1	12.7	A13	814.9	12.4
B2	255.7	4.3	B8	256.1	4.3
B4	257.1	4.3	B10	257.6	4.3
B6	254.1	4.2	B12	253.3	4.4
C2	360.2	7.8	C8	359.2	7.9
C4	373.7	8.0	C10	363.5	7.8
C6	364.8	8.0	C12	375.9	7.7
D2	864.5	13.3	D8	913.8	13.1
D4	906.6	13.3	D10	914.2	13.1
D6	898.5	13.2	D12	905.6	13.5
E2	745.5	12.6	E8	761.4	12.4
E4	728.3	12.3	E10	724.3	12.6
E6	711.6	12.3	E12	746.4	12.7

Table 2: Measured initial characteristics of selected lamps

2.3. Luminous flux

2.3.1. Accelerated ageing at 45°C

Flux variation against operation time

The luminous flux variation after each accelerated ageing 2-month cycle is given in the following table 3 in term of percentage of deviation from the initial flux; the operation time is the accumulated time of operation under thermal stress. To better visualize the behavior and dispersion five graphs for each lamp type are given in figure 1 next page.

Batch 1 – 45° / lamp ID	Deviation from initial flux (%) versus operation time (h)			
	100 h	1488 h	2785 h	4318 h
Lamp A2	0.00	2.35	2.77	2.69
Lamp A4	0.00	1.67	1.89	1.75
Lamp A6	0.00	1.65	2.02	1.99
Lamp B2	0.00	-5.15	-8.16	-10.43
Lamp B4	0.00	-3.53	-5.13	-6.50
Lamp B6	0.00	-4.92	-7.12	-8.88
Lamp C2	0.00	-3.07	-3.65	-5.20
Lamp C4	0.00	-2.42	-3.22	-4.39
Lamp C6	0.00	-2.82	-3.06	-4.03
Lamp D2	0.00	0.54	0.92	1.98
Lamp D4	0.00	-2.25	-2.32	-0.81
Lamp D6	0.00	-1.03	1.01	0.58
Lamp E2	0.00	-1.41	-2.61	-3.80
Lamp E4	0.00	-1.80	-2.68	-5.90
Lamp E6	0.00	-0.85	-1.18	-3.38
Lamp A average	0.00	1.89	2.23	2.14
Lamp B average	0.00	-4.53	-6.80	-8.60
Lamp C average	0.00	-2.77	-3.31	-4.54
Lamp D average	0.00	-0.91	-0.13	0.58
Lamp E average	0.00	-1.35	-2.16	-4.36

Table 3: Flux variation against operation time under thermal stress at 45°C

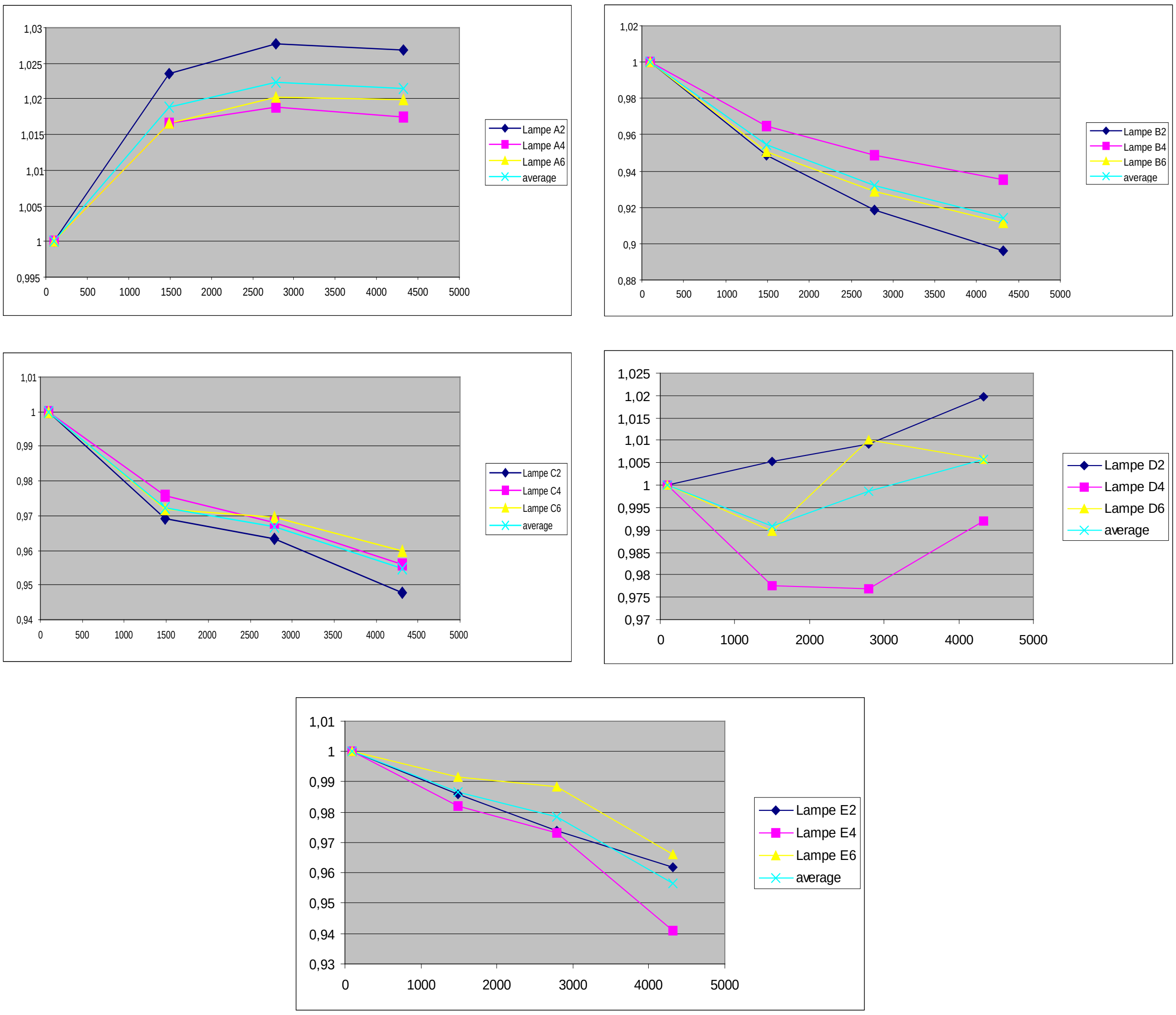

Figure 1: Graph of luminous flux against operation time under thermal stress at 45°C

Comparison with natural ageing

To compare with the luminous flux of the lamps under natural ageing data we first computed an acceleration factor. Due to the low number of samples/units we applied the recommended method for lumen maintenance life projection of IESNA TM 21-11 [1] not on each type but on the averaged data over all the lamps excepted the lamps type D which are very instable as shown on the figure 1 above. Then we used two possible simple methods to compute an linear acceleration factor.

Method 1: the time coefficient (λ) applied on accelerated data yielding to the same exponent (α) of the exponential function of natural data can represent an unique time acceleration factor :

- Exponential function for natural ageing: $\Phi n(t) = B\exp(-\alpha t)$
- Exponential function for accelerated ageing : $\Phi a(t) = B'\exp(-\alpha t') \quad t' = \lambda t$

Method 2: to compute lifetime projections for natural and accelerated ageing for the two lumen maintenance values of 70% and 50%. The average ratio of natural lumen maintenance life (L_{70},L_{50}) divided by the accelerated lumen maintenance life (L'_{70}, L'_{50}), computed in the same way, can represent an average acceleration factor : $\lambda = 0.5\ (L_{50}/L'_{50} + L_{70}/L'_{70})$.

Method 1	Method 2 L70	Method 2 L50	Method 2 average
1.340	1.344	1.345	1.345

Table 4: Acceleration factors for thermal stress at 45°C

The comparative graphs of natural ageing and accelerated ageing of averaged flux of the samples of same type of lamps are presented below on figure 2. To observe the match with natural ageing curves the operation time for accelerated ageing is multiplied by the accelerating factor found by method 2 : 1.345.

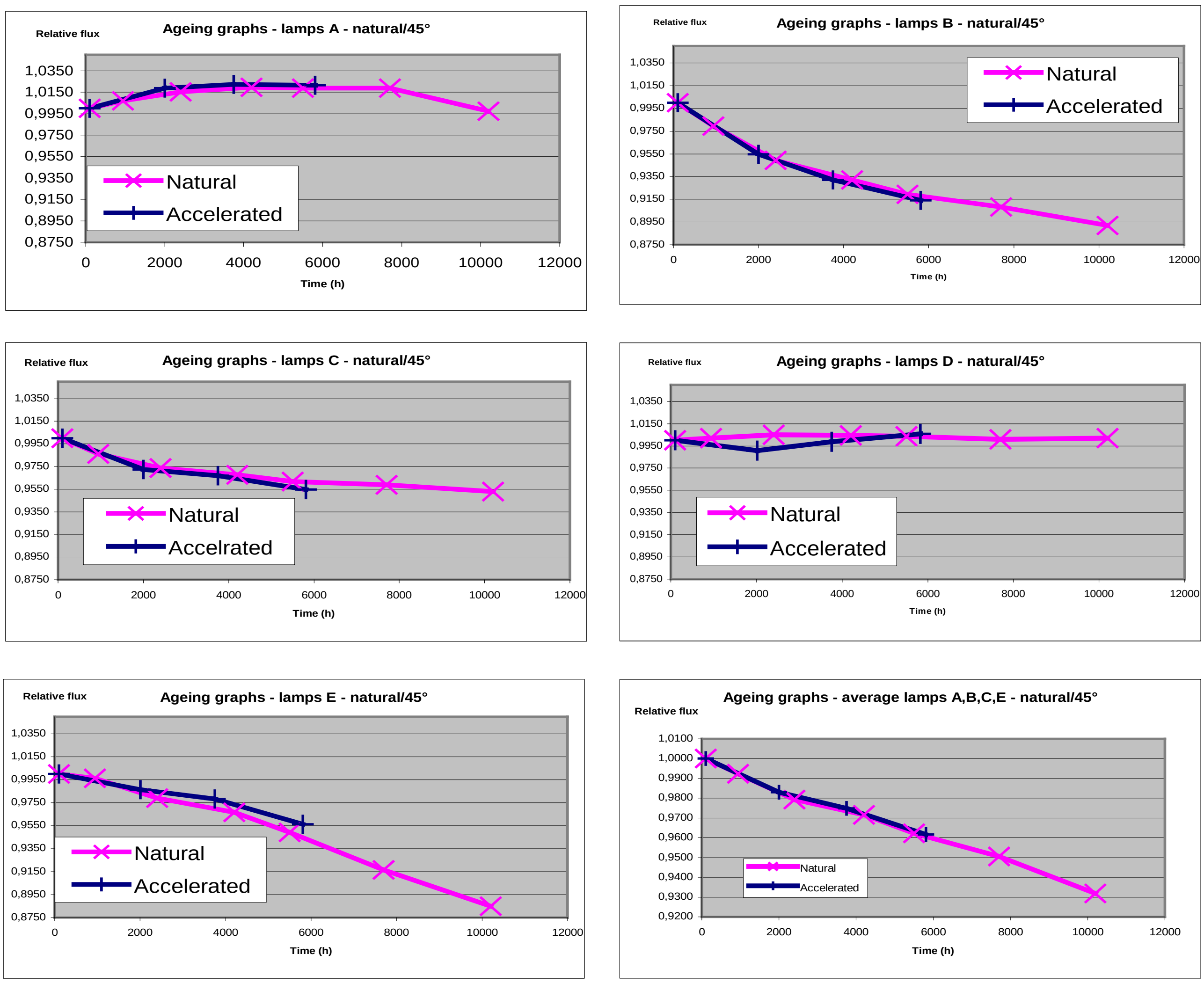

Figure 2: Comparative graphs of natural and accelerated ageing at 45°C

Comments

We observe a relative good match between the average curves of natural and accelerated ageing at 45°C with an acceleration factor of 1.345. We observe small differences for each samples lamp type but with same behavior against time for all lamp types and with more dispersion for lamps D. We suppose for that lamp that the added red LEDs to white LEDs account for the instability of the D lamps . The averaged curves on all lamps except the D lamps for natural and accelerated ageing lamp match perfectly, see graph at the bottom-right of figure 2. For lamps D, even with a strong dispersion the trends of averaged curves, for natural and accelerated, on few samples (4 for natural and 3 for accelerated) are significantly close. All those results demonstrates the potential of accelerated ageing by thermal stress and justify the second experiment at a higher temperature.

2.3.2. Accelerated ageing at 60°C

Flux variation against operation time

The luminous flux variation after each accelerated ageing cycle is given in the following table 4 in term of percentage of deviation from the initial flux, the operation time is the accumulated time under thermal stress. To better visualize the behavior and dispersion five graphs for each lamp type are given figure 3.

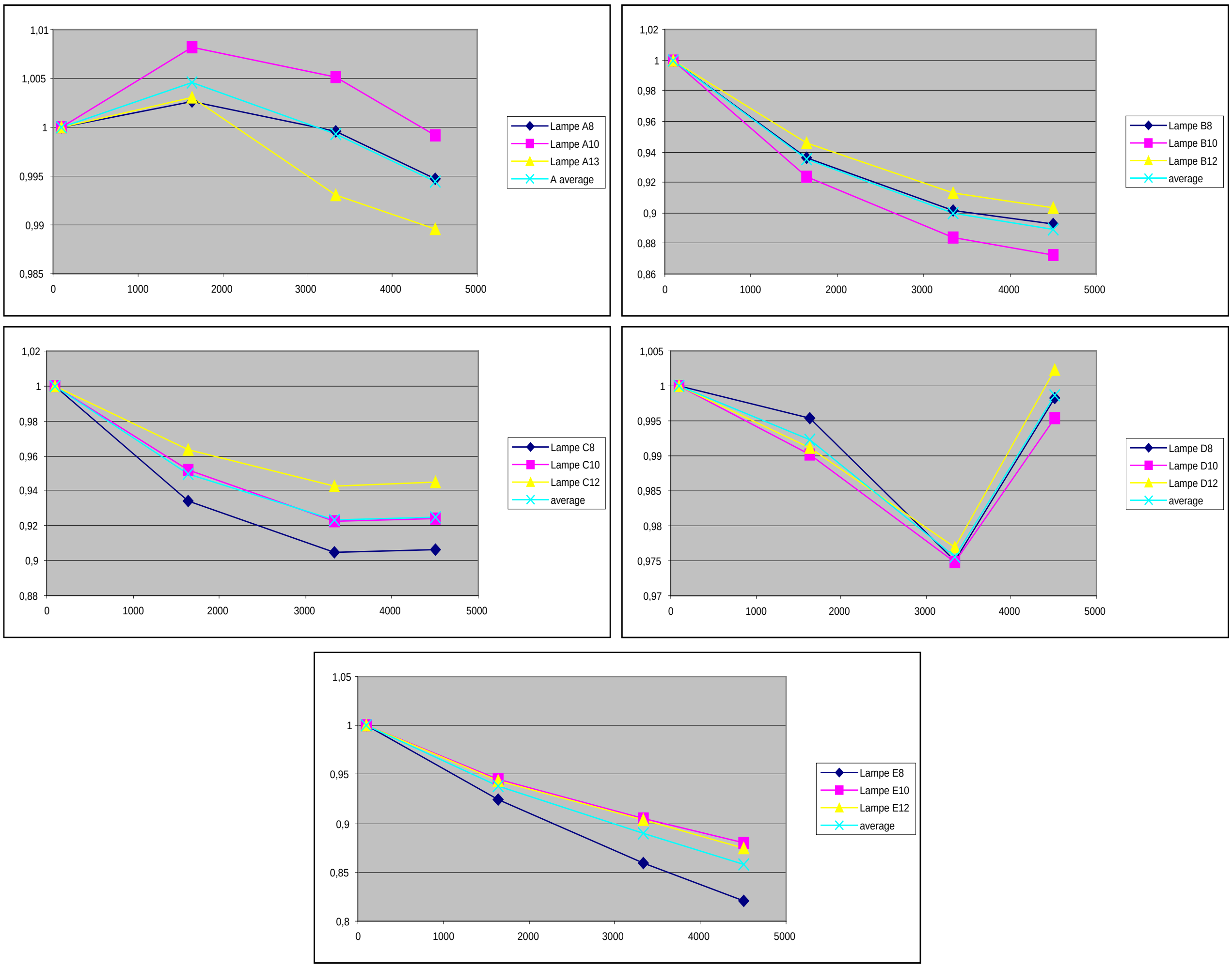

Figure 3: Graph of luminous flux against operation time under thermal stress at 60°C

Batch 2 / lamp ID	Deviation from initial flux (%) versus operation time (h)			
	100 h	1640 h	3338 h	4508 h
Lamp A8	0.00	0.26	-0.04	-0.53
Lamp A10	0.00	0.83	0.52	-0.09
Lamp A13	0.00	0.30	-0.70	-1.04
Lamp B8	0.00	-6.38	-9.80	-10.75
Lamp B10	0.00	-7.61	-11.62	-12.74
Lamp B12	0.00	-5.40	-8.73	-9.69
Lamp C8	0.00	-6.58	-9.53	-9.38
Lamp C10	0.00	-4.83	-7.77	-7.62
Lamp C12	0.00	-3.62	-5.77	-5.53
Lamp D8	0.00	-0.46	-2.49	-0.18
Lamp D10	0.00	-0.99	-2.51	-0.46
Lamp D12	0.00	-0.89	-2.31	0.23
Lamp E8	0.00	-7.54	-14.11	-17.96
Lamp E10	0.00	-5.48	-9.46	-12.00
Lamp E12	0.00	-5.66	-9.70	-12.57
Lamp A average	0.00	0.46	-0.07	-0.55
Lamp B average	0.00	-6.47	-10.05	-11.06
Lamp C average	0.00	-5.01	-7.69	-7.51
Lamp D average	0.00	-0.78	-2.44	-0.14
Lamp E average	0.00	-6.23	-11.09	-14.18

Table 5: Flux variation against operation time under thermal stress at 60°C

Comparison with natural ageing

We computed the acceleration factors, reported in table 6, with the same methods as those applied for 45°C (see 2.3.1)

Method 1	Methode 2 L70	Method 2 L50	Method 2 average
2.911	2.970	2.958	2.964

Table 6: Acceleration factors for thermal stress at 60°C

The comparative graphs of natural ageing and accelerated ageing of averaged flux of the samples of the same type of lamp are presented below on figure 4. To observe the match with natural ageing curves the operation time for accelerated ageing is multiplied by the accelerating factor found by method 2 : 2.964.

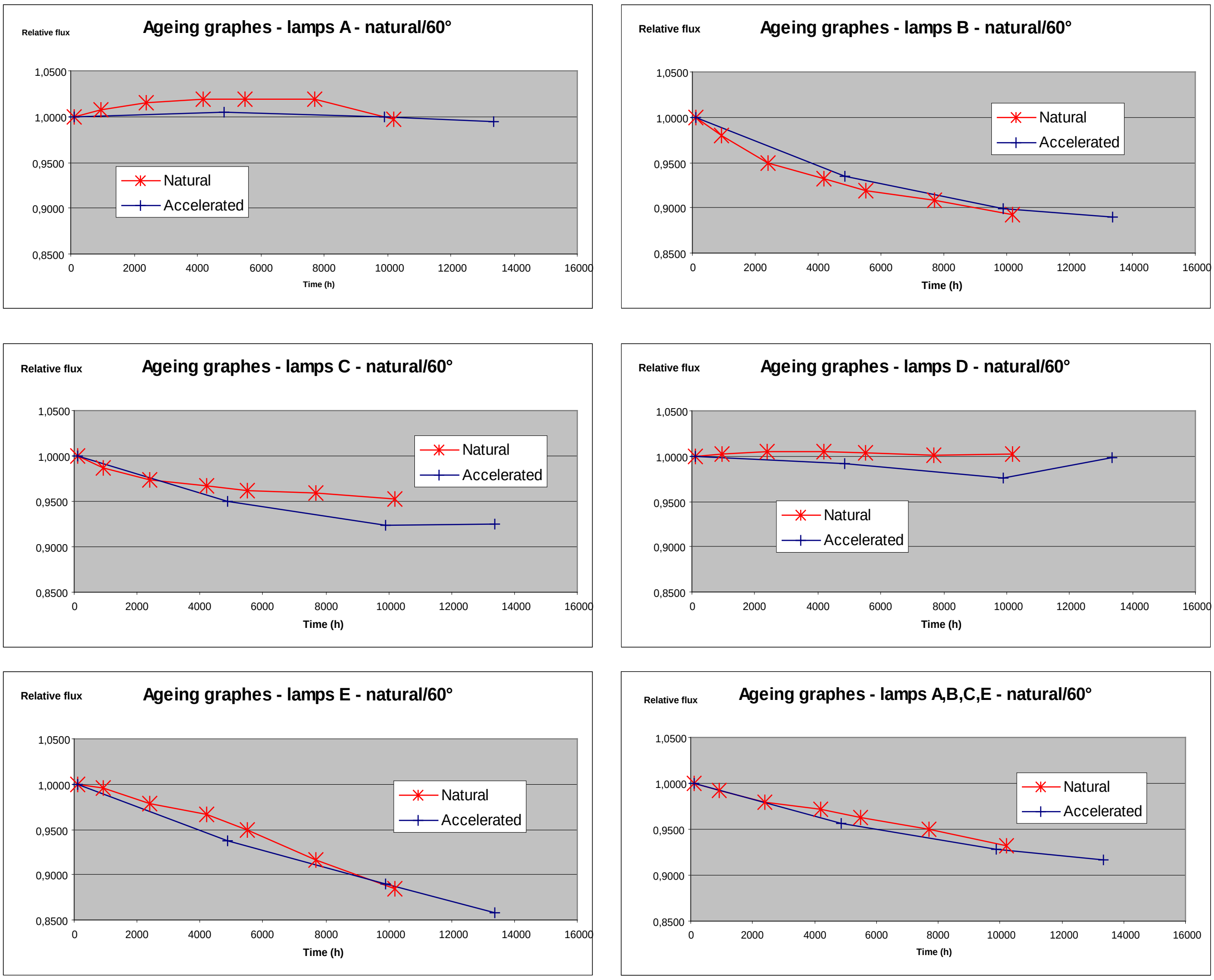

Figure 4: Comparative graphs of natural and accelerated ageing at 60°C

Comments

The match between the average curves of natural and accelerated ageing at 60°C with an acceleration factor of 2.964 is not so good than the one obtained with 45°C. Curves shapes, very similar for natural and accelerated ageing at 45°C are somewhat different for 60°C. We do not know the poorer matching accounts for differences/dispersion in lamps or if the temperature of 60°C triggers deprecating processes that will not occur with natural ageing. The relative differences on flux variation at operation time of 10 000 hours, or equivalent for accelerated, is less than 1% for 3 types { A, B, E } and the average on all lamps excepts type D and around 2.5% for the type C.

Both the two accelerated experiments demonstrated, with very few samples, that thermal stress could yield to relatively accurate accelerated ageing. More samples/units and types of lamps are needed to validate the method and intermediate test temperatures : 45°C leading to slow acceleration with very good matching for the test types of lamps and 60°C leading to faster acceleration with a more dispersed matching quality.

2.4. Spectral density of flux

2.4.1. Accelerated ageing at 45°C

To clearly see how the SPDs evolved from the beginning till the end of accelerated ageing we plot only the averaged curves on the samples of the same lamp type, the SPDs are normalized to the luminous flux.

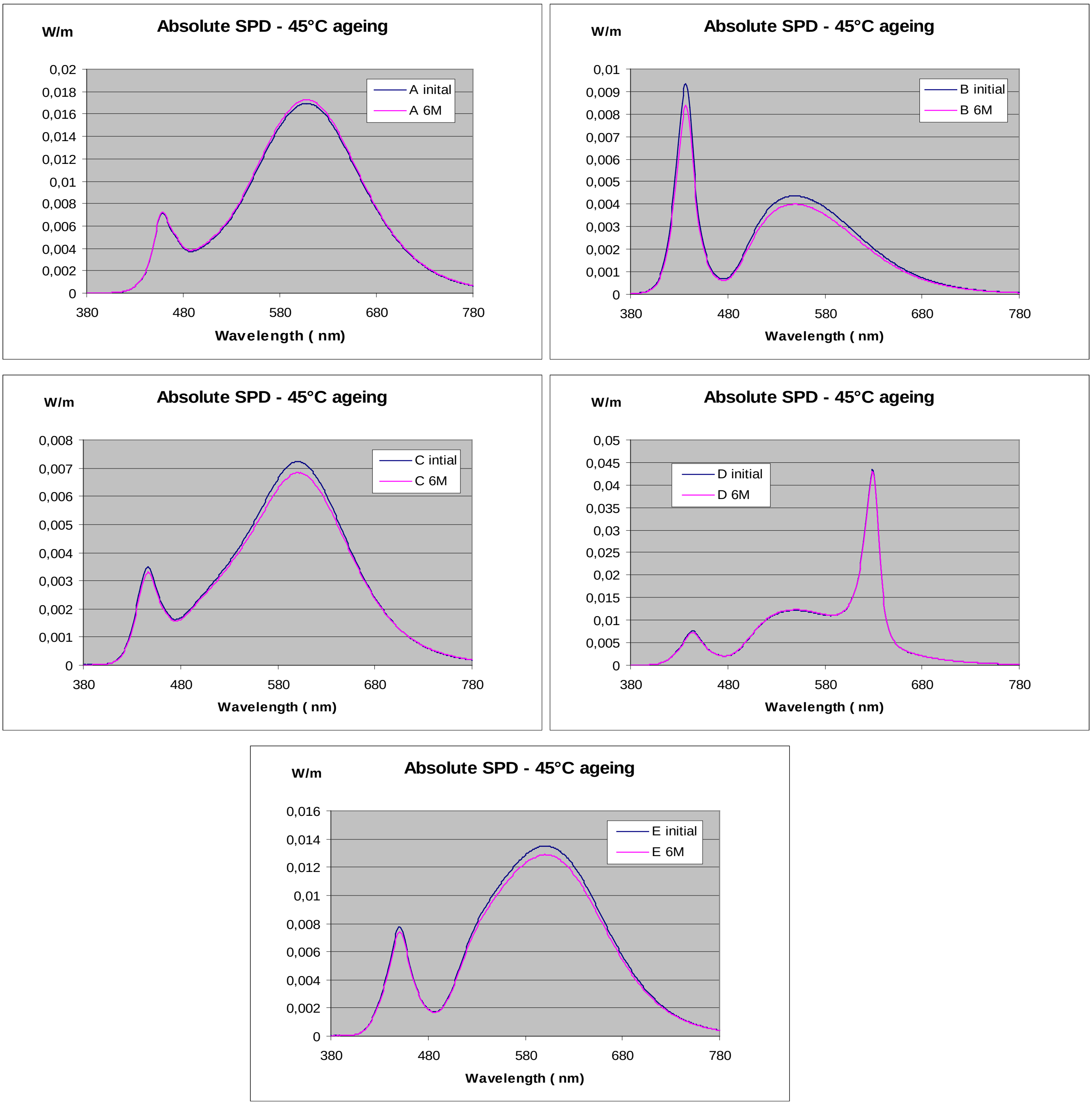

Figure 5: Graphs of SPDs before and after accelerated ageing at 45°C

We represent in the following figure 6 the plot CTT in Kelvin against the operation time for each lamp.

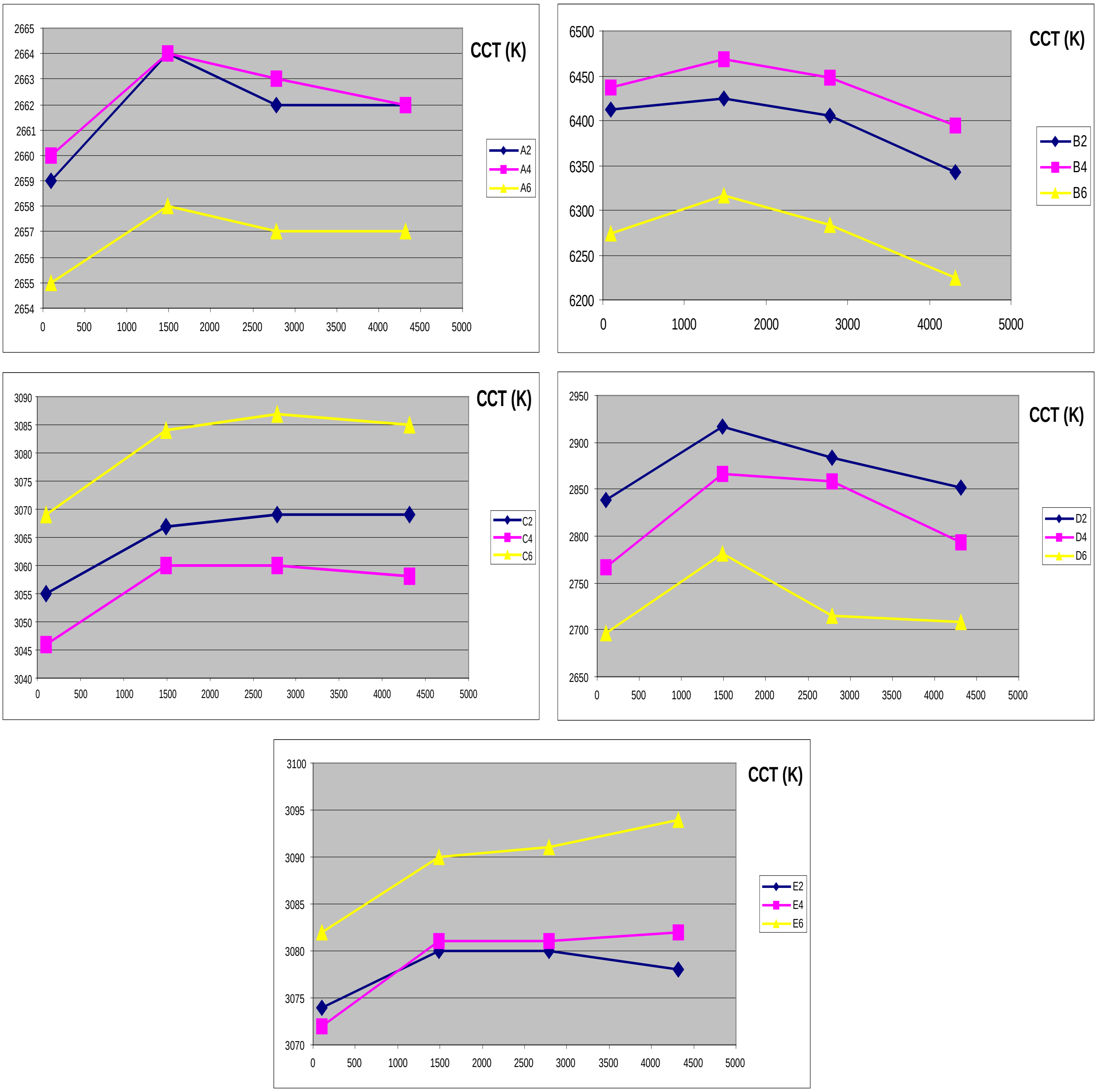

Figure 6: Plots of CCT against operation time at 45°C

Comments

We can clearly observe, on figure 5, for each lamp type the variation of the blue peak of the LED in comparison to the variation of the phosphor-converted peak and red peak variation that change the chromaticity coordinates (x,y) and then the CCT.

batch 1 - 45°C (x,y) evolution table		operation time			
		100 h	1488 h	2785 h	4318 h
		values	Deviations from initial values		
x	A2	**0,4598**	-0,0001	-0,0001	**0,0000**
	A4	**0,4596**	-0,0002	-0,0002	**-0,0001**
	A6	**0,4605**	-0,0002	-0,0001	**-0,0001**
y	A2	**0,4053**	0,0003	0,0002	**0,0004**
	A4	**0,4051**	0,0001	0,0001	**0,0001**
	A6	**0,4061**	0,0001	0,0001	**0,0001**
x	B2	**0,3140**	-0,0002	0,0001	**0,0011**
	B4	**0,3136**	-0,0005	-0,0002	**0,0007**
	B6	**0,3163**	-0,0007	-0,0002	**0,0008**
y	B2	**0,3322**	-0,0005	0,0003	**0,0018**
	B4	**0,3320**	-0,0010	-0,0003	**0,0010**
	B6	**0,3359**	-0,0013	-0,0001	**0,0014**
x	C2	**0,4301**	-0,0011	-0,0011	**-0,0009**
	C4	**0,4317**	-0,0009	-0,0007	**-0,0002**
	C6	**0,4304**	-0,0012	-0,0011	**-0,0007**
y	C2	**0,3963**	-0,0008	-0,0006	**-0,0003**
	C4	**0,3987**	-0,0003	0,0002	**0,0010**
	C6	**0,3987**	-0,0006	-0,0003	**0,0003**
x	D2	**0,4477**	-0,0038	-0,0016	**0,0007**
	D4	**0,4520**	-0,0054	-0,0047	**-0,0005**
	D6	**0,4555**	-0,0049	-0,0005	**0,0004**
y	D2	**0,4056**	0,0024	0,0025	**0,0030**
	D4	**0,4047**	0,0022	0,0025	**0,0024**
	D6	**0,4023**	0,0016	0,0013	**0,0022**
x	E2	**0,4315**	-0,0005	-0,0003	**-0,0001**
	E4	**0,4316**	-0,0008	-0,0006	**-0,0008**
	E6	**0,4295**	-0,0007	-0,0007	**-0,0009**
y	E2	**0,4016**	-0,0003	0,0000	**0,0003**
	E4	**0,4015**	-0,0005	-0,0002	**-0,0005**
	E6	**0,3984**	-0,0005	-0,0003	**-0,0006**

Table 7: Evolution of chromaticity coordinates (x,y) for 45°C ageing test

Comments

The maximum and minimum deviations from initial coordinates (x,y) for all the lamps are respectively 0.003 and -0.0009.

2.4.2. Accelerated ageing at 60°C

To clearly see how the SPDs evolved from the beginning till the end of accelerated ageing we plot only the averaged curves on the samples of the same lamp type, the SPDs are normalized to the luminous flux.

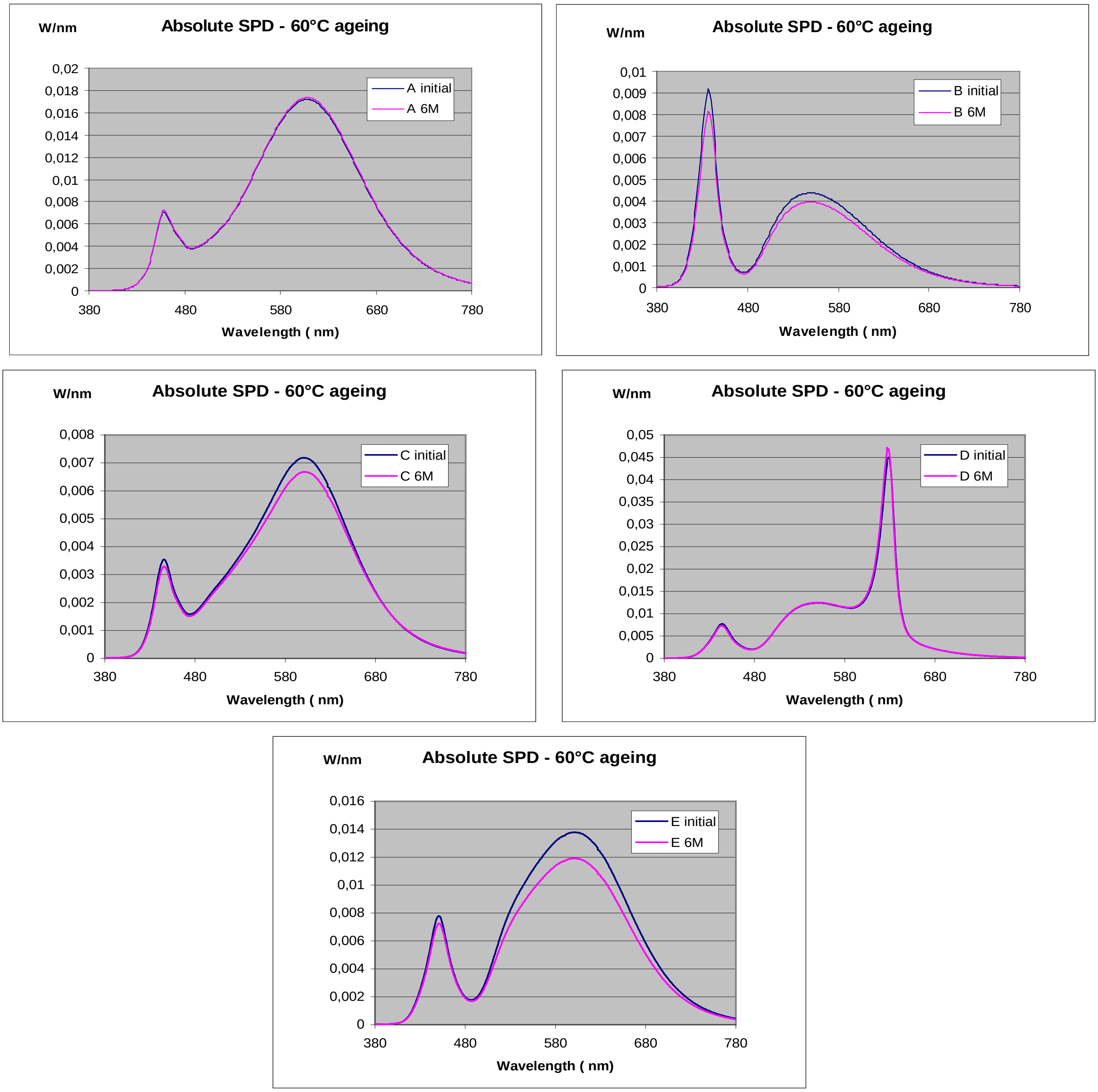

Figure 7: Graphs of SPDs before and after accelerated ageing at 60°C

We represent in the following figure 6 the plot of CTT in Kelvin against the operation time for each lamps, the 4-month measurements are missing due a malfunctioning part.

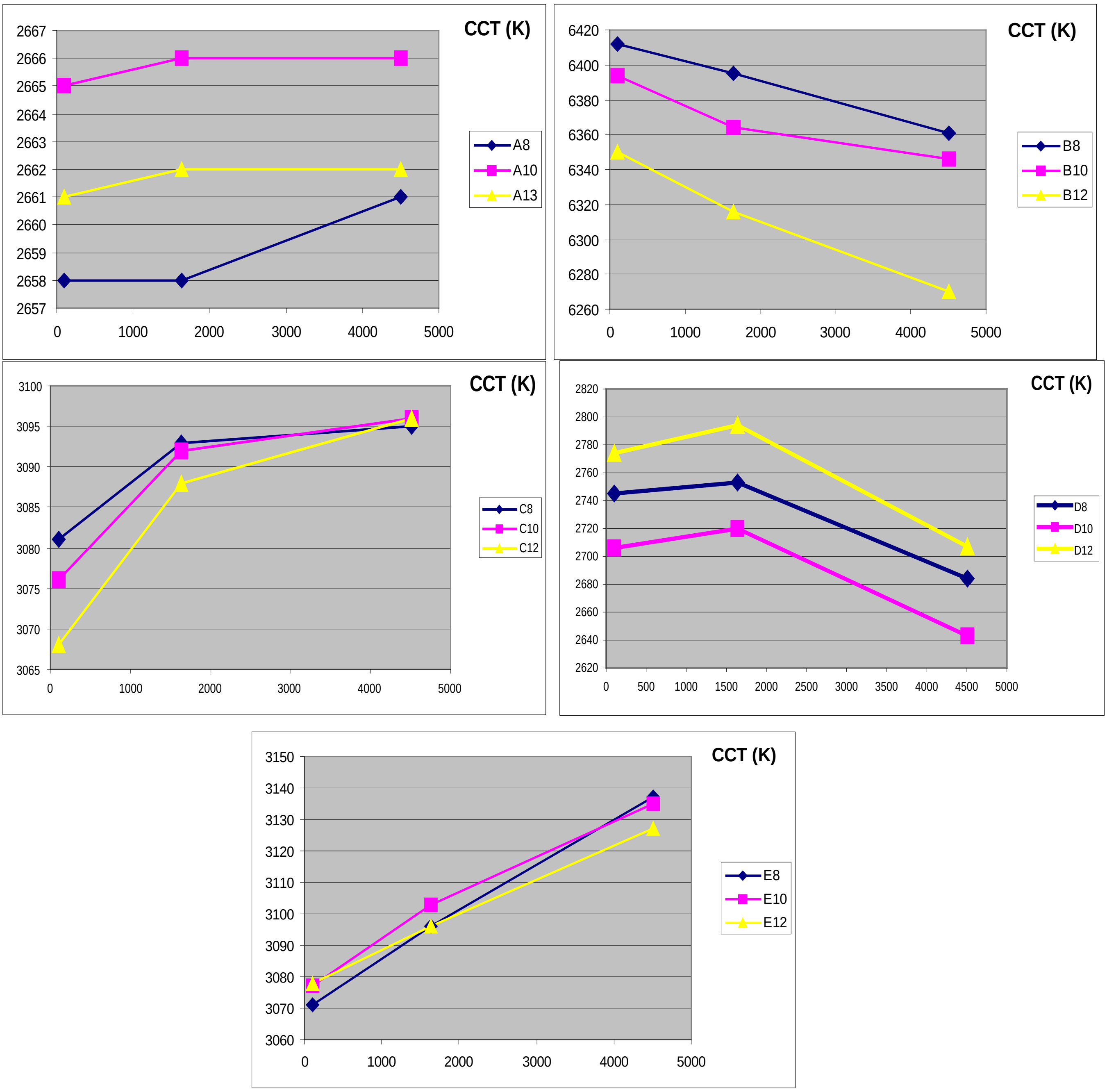

Figure 8: Plots of CCT against operation time at 60°C

Comments

We can clearly observe, on figure 7, for each lamp type the variation of the blue peak of the LED in comparison to the variation of the phosphor-converted peak and red peak variation that change the chromaticity coordinates (x,y) and then the CCT.

batch 2 - 60°C (x,y) evolution table		operation time (h) 100 h	1640 h	4508 h
		values	deviations from initial values	
x	A8	0,46069927	0,0000	-0,0005
	A10	0,45992507	-0,0002	-0,0005
	A13	0,46010109	-0,0001	-0,0005
y	A8	0,40677467	-0,0001	-0,0004
	A10	0,40621016	-0,0001	-0,0007
	A13	0,4060447	-0,0001	-0,0006
x	B8	0,31405712	0,0002	0,0008
	B10	0,31422135	0,0005	0,0008
	B12	0,31500403	0,0005	0,0013
y	B8	0,33204826	0,0007	0,0015
	B10	0,3334198	0,0011	0,0015
	B12	0,3340712	0,0012	0,0021
x	C8	0,42912879	-0,0007	-0,0004
	C10	0,42924415	-0,0009	-0,0006
	C12	0,43198955	-0,0012	-0,0011
y	C8	0,39740074	-0,0001	0,0009
	C10	0,39713175	0,0000	0,0010
	C12	0,40195467	-0,0001	0,0011
x	D8	0,39740074	-0,0001	0,0009
	D10	0,39713175	0,0000	0,0010
	D12	0,40195467	-0,0001	0,0011
y	D8	0,40492994	0,0024	0,0018
	D10	0,40348835	0,0027	0,0022
	D12	0,40443151	0,0029	0,0021
x	E8	0,43200693	-0,0021	-0,0063
	E10	0,43030589	-0,0022	-0,0051
	E12	0,43120995	-0,0014	-0,0044
y	E8	0,4023952	-0,0015	-0,0058
	E10	0,39943777	-0,0015	-0,0041
	E12	0,40154889	-0,0010	-0,0036

Table 8: Evolution of chromaticity coordinates (x,y) for 60°C ageing test

Comments

The maximum and minimum deviations from initial coordinates (x,y) for all the lamps are respectively 0.0022 and -0.0063.

2.5. Electrical characteristics

2.5.1. Power consumption

The measured power consumption of the lamps, before and after ageing , of the two batches are presented in the table 7 below. The differences between measured consumptions before and after accelerated ageing are quite low, the maximum absolute difference is smaller or equal to 0,2 W. We observe a weak upward trend for all lamps excepted for lamps E. Thus the efficacy deprecation of the lamps principally account for the flux deprecation of the lamps .

lamp ID	Power consumption			lamp ID	Power consumption		
batch 1	initial	final	difference	batch 2	initial	final	difference
45°C	(W)	(W)	(W)	60°C	(W)	(W)	(W)
A2	12.6	12.5	0.1	A8	12.4	12.4	0.0
A4	12.5	12.5	0.0	A10	12.7	12.7	0.0
A6	12.7	12.6	0.1	A13	12.4	12.4	0.0
B2	4.3	4.2	0.1	B8	4.3	4.2	0.1
B4	4.3	4.3	0.1	B10	4.3	4.3	0.0
B6	4.2	4.2	0.0	B12	4.4	4.3	0.1
C2	7.8	7.6	0.2	C8	7.9	7.7	0.2
C4	8.0	7.8	0.2	C10	7.8	7.6	0.2
C6	8.0	7.7	0.2	C12	7.7	7.5	0.2
D2	13.3	13.1	0.2	D8	13.1	12.9	0.2
D4	13.3	13.2	0.1	D10	13.1	13.0	0.1
D6	13.2	13.1	0.1	D12	13.5	13.4	0.1
E2	12.6	12.7	-0.1	E8	12.4	12.5	-0.1
E4	12.3	12.5	-0.2	E10	12.6	12.7	-0.1
E6	12.3	12.4	-0.1	E12	12.7	12.8	-0.1

Table 9: Power consumption of the lamps before and after accelerated ageing at 45°C and 60°C

2.5.2. Current delivered to PCBs

The extra lamps AX have been altered to extent the wire soldered on the PCB. The extension loops pass trough two holes dug in the plastic diffuser or the plastic body of the lamp. Those loops allowed us to probe the current delivered to the PCB were the LED are soldered using a current clamp. The PCBs support the LEDs but also capacitors for some lamps, those capacitors filter the pulsed current waveforms delivered by electronic units. We will consider only average currents assuming that evolution of average radiated fluxes pertain to evolution of average currents.

Those extra lamps have been aged in the same way that the lamps of batch 1 under thermal stress at 45°C. We assume that the minor modification brought did not change the ageing processes, and that the altered lamps were in a similar thermal and electrical state than unaltered lamps while ageing at elevated ambient temperature.

current (mA)	**operation time at 45°C**			
lamp ID	**100 h**	**1488 h**	**2785 h**	**4318 h**
lamp AX	203.8	205.1	202.8	201.6
LAMP B17	346.9	345.1	347.9	347.7
lamp CX	302.3	303.9	302.8	302.9
lamp DX	362.0	365.8	362.2	357.9
lamp EX	349.3	357.3	356.3	351.9

Table 10: Current evolution against time for extra lamps aged at 45°C

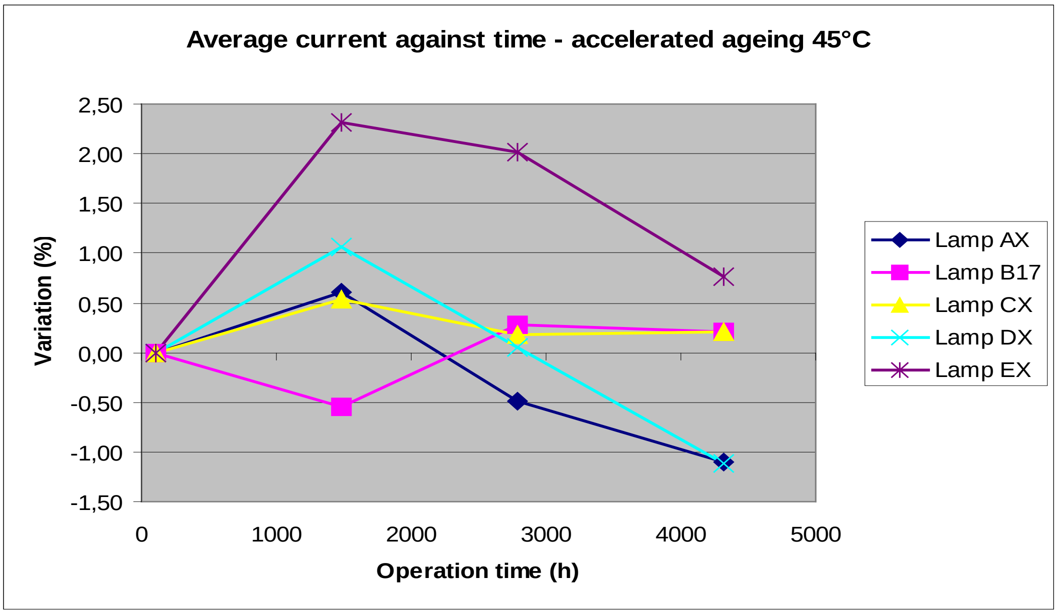

Figure 9: Plot of LED currents against time for ageing at 45°C

The current and flux for each lamp type are plotted in the graphs of figure 10 to see how the flux evolve with the current provided to the LEDs.

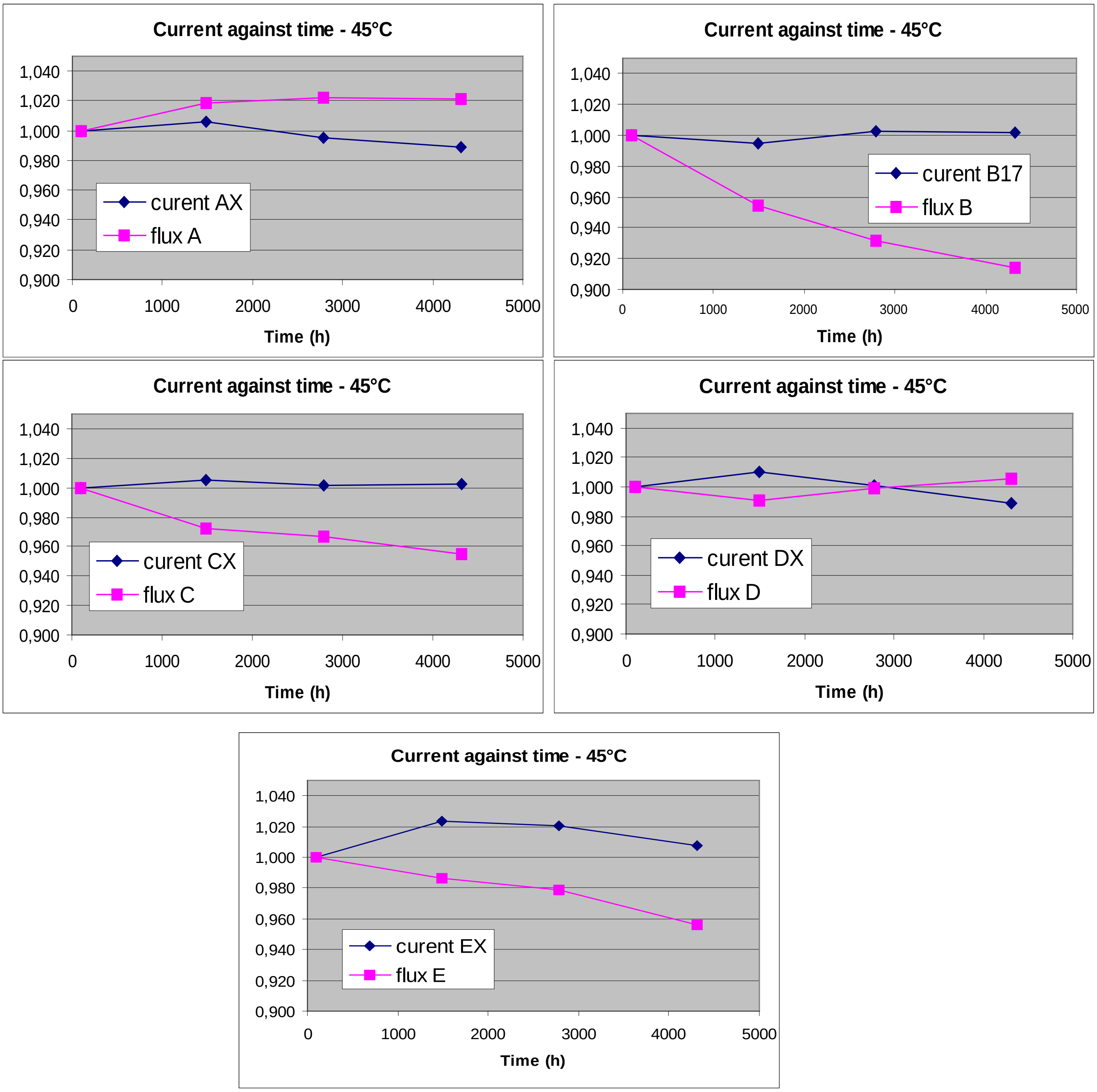

Figure 10: Plot of fluxes and currents against operation time for ageing at 45°C

Comments

For all lamps the current either stabilizes or gradually decreases but not beyond –2%. Then the electronic units of the selected lamps contributed to flux deprecation in a very limited part.

3. Main conclusion

The present study demonstrated the potential of thermal stress to accelerate ageing of LED-based lamps using basic facilities. The thermal stress is usually proposed, for lighting products, as an endurance test – see the IEC/PAS [2] combining electrical cycling, thermal shock and thermal cycling at 45°C. Beyond this endurance test we observed a very good matching between natural and accelerated flux evolution with the elevated temperature of 45°C (figure 2,11) and a faster acceleration at elevated temperature of 60°C but with a lower matching performance (figure4). The estimated acceleration factors with respect to L50/L70 at 40°C and 60°C are respectively 1.34 and 2.96. More samples and lamp types are needed to confirm this method which can speed up the very long industrial and laboratory testing of SSL. The accelerated ageing at elevated temperature can be used for lumen maintenance specification but also for maintenance of colour specification (CCT, (x,y), CRI). A method proposed to follow up the current delivered to LEDs with the lamps aged with minor alteration, the results show that the current evolution can account for flux deprecation for some lamps.

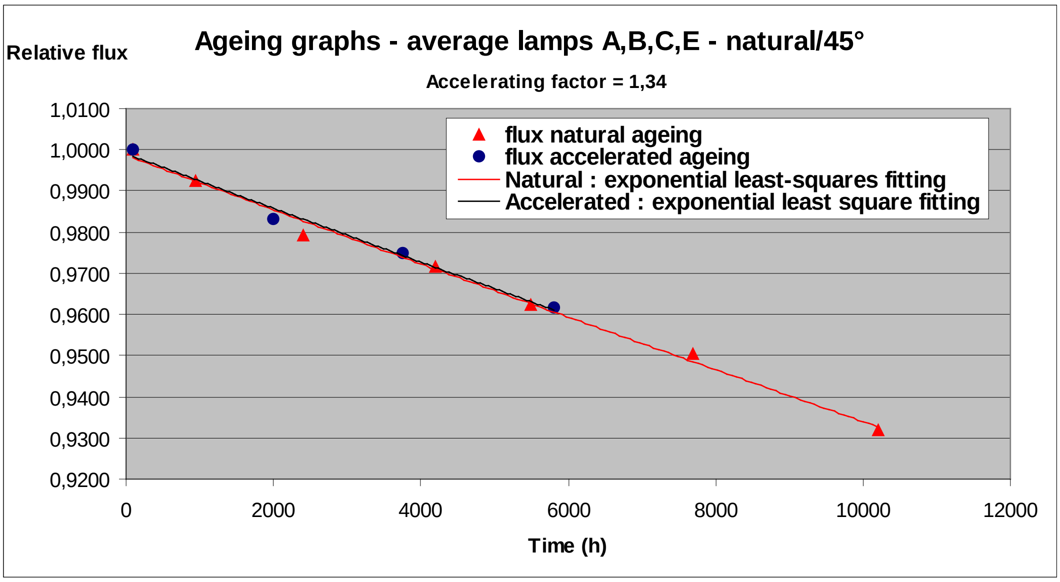

Figure 11 : Comparison, natural and accelerated 45°C, of lifetime projection with exponential curve-fitting

References

[1] IESNA TM 21-11 - Projecting Long Term Lumen Maintenance of LED Light Sources

[2] IEC/PAS 62612 - Self-ballasted LED-lamps for General Lighting Services.