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Luminesans (Parlayan) İpliklerin Morfolojik ve Parlama Özellikleri ile Parlama Dayanıklılığının İncelenmesi

Analysis of Morphology, Luminescent Properties and Illuminating Durability of Photoluminescent Fibre

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ANALYSIS OF MORPHOLOGY, LUMINESCENT PROPERTIES AND ILLUMINATING DURABILITY OF PHOTOLUMINESCENT FIBRE

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ABSTRACT: This study researched morphology, surface structures, tensile properties and variations in luminance intensity and decay characteristics of yarn and knitted fabric samples containing photoluminescent materials. The luminescent yarn and fabrics were exposed to four different light sources (UV, TL84, D65 and F) at 1 and 5 minutes, and dependence of initial luminance intensity values and decaying with time of the samples on light source type for exposing, activation time, form and weight of the samples were measured. In the study, the influence of rubbing and washing effects met during daily usage or textile processes on afterglowing were also analysed.

Keywords: Photo-luminescent material, after-glowing, illumination, functional fibre.

LUMİNESANS (PARLAYAN) İPLİKLERİN MORFOLOJİK VE PARLAMA ÖZELLİKLERİ İLE PARLAMA DAYANIKLILIĞININ İNCELENMESİ

ÖZET: Bu çalışmada, luminesans malzeme içeren iplik ve kumaş numunelerinin morfolojisi, yüzey ve gerilme özellikleri ile parlama yoğunluğu ve emisyon (yayınım) bozunma karakterleri analiz edilmiştir. Luminesans (parlayan) iplik ve kumaşları dört farklı ışık türü (UV, TL84, D65 ve F) ile 1 ve 5 dakika olmak üzere iki farklı sürede aktive (şarj) edilmiştir. Aktivasyon süresi, ışık türü, numune formu ve ağırlığının, başlangıç ışık (parlama) yoğunluğu ve parlaklığın zamana bağlı olarak değişimine etkisi belirlenmiştir. Çalışmada, günlük kullanım veya tekstil prosesleri sırasında karşılaşılan sürtme ve yıkama etkilerinin parlama özelliklerine etkisi incelenmiştir.

Anahtar kelimeler: Luminesans malzeme, parlama, parlaklık, fonksiyonel lif.

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1. INTRODUCTION

Photoluminescent materials have characteristics of high luminescent brightness, long afterglow time, good chemical stability, no pollutions etc. Afterglowing features of luminescent materials increase visibility of any object or place in darkness. Therefore, these materials are widely applied in luminescent paint, night illumination, and instrumental display to raise the safety and also to incorporate the visual aesthetic elements. Today, they have large usage areas such as protective clothing for fire-fighters and chemical workers, athletic and hunting gear, ropes and cords, life vests, carpets for theatres, airplane interiors etc. [1-2]. When luminescent materials are left under any visible light, the light energy will be absorbed and stored in the material, which makes the material luminous in darkness for a certain time. They can emit a series of coloured lights in the darkness, such as yellow, blue and green. This cycle can be repeated limitlessly. Photoluminescent materials can also be used as incorporated into textile structures by painting, coating or laminating. However, now, there have been attempts aimed to combine the fibre-forming polymer and rare-earth photoluminescent materials during fibre spinning process [3-4]. Direct incorporation of the photoluminescent materials into fibres overcomes many of the difficulties with coating methods and provides enough durability and good afterglow properties.

In recent years, luminescent fibre production has become very important because of the afterglowing characteristics of the fibre [5] and hence researchers and companies worked on photoluminescent fibre production. Ge et al. (2012) [5] prepared luminescent fibre by using rare-earth strontium aluminate as the rare-earth luminescent material, fibre-forming polymer PET as the matrix. The microstructure, composition and properties of rare-earth luminescent fibre were studied. In another work, Yan et al. (2012) [6] produced the luminous fibre by melt spinning mixturing complex strontium aluminate phosphor and polyethylene terephthalate. Bracko et al. (2011) [3] researched impregnation dyeing of spun yarn with photoluminescent pigments and analysed luminance level of the yarns. Cheng et al. (2010) [4] fabricated photoluminescence fibre by a simple electrospinning combined with sol–gel process and characterized the fibres. Mishra et al. (2009) [7] produced phosphor-based polymer composites with melt mixing and extrusion method. Morphology, luminescent properties, and Hamburg wheel test (HWT) of synthesized hybrid material were studied using various polymer matrices. Peng et al. (2006) [8] worked on grafting emulsion polymerization of methyl methacrylate onto the surface of luminescent materials and analysed Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), and photoluminescent properties of the PMMA/rare earth composite luminescent materials were measured. Shim et al. (2004) [2] worked on the production of photoluminescent fibres with sheath-core morphology to impart good mechanical properties.

The main properties of the luminescent fibres are good initial brightness and long-lasting afterglowing. Therefore, the researchers in their studies focused on photoluminescent fibre production with different methods and also measurement of luminescent intensity. On the other hand, one of the primary problems of photoluminescent yarns is low abrasion stability which prevents these yarns to be further used [3]. In literature, no reports have been found for the abrasion resistance of phosphorescence characteristics. Therefore, in present study, we aimed to determine illumination characteristic polyester fibre having photoluminescent materials. In the study, the dependence of decay characteristics and durability of luminescence against some effects such as rubbing, washing of photoluminescent textile products were researched. However, there are not so many studies about the effects of some parameters such as light source type and exposing time for the storage and sample form on afterglowing. In the study, the relationships between analysed parameters and luminance, and also morphology and tensile properties of the fibres were investigated in detail.

2. MATERIAL AND METHOD

In the study, polyester yarn, a mixture of curtisium photoluminous material and polymer, was used. Yarn fineness was 300 denier (15 filaments). At first, the yarn was knitted on sample knitting machine and knitted fabrics were obtained. In present study, three types of experiments were realized. In the first set of the experiments, photoluminescent yarn properties were analyzed, yarn appearances and tensile properties were determined. Polyester and luminescent fibres were analysed by Motic BX optical microscopy. The

breaking tenacity and elongation of samples were tested by Llyod LRK 5 Plus tensile strength tester with clamping length of 20 mm and tensile speed of 20 mm/min in the standard atmospheric conditions.

In the second experiment set, the effect of charging time, light source, fabric weight and sample form on illuminating behaviour were studied. In this part, the knitted fabrics were cut at two different dimensions and the weights of the fabric were measured. Fabric dimensions are 22 cm × 14 cm, and 22 cm × 21 cm. The weights of the fabrics were 10 g and 15 g, respectively. But, it is necessary to state that the fabrics had the same (325 g/m^2) weight in gram per m^2. For the comparison, different fabric dimensions were indicated with fabric weights. In the determination of photoluminescence, similar sample preparation procedure was followed as reported by Shim et al. (2004) [2] and Bracko et al. (2011) [3]. The fabrics were fixed on white paper of 2 x 2 cm in size without any crease. And then the samples were charged for different times. The fabrics were exposed to the illumination sources. UV, TL84, D65 and F illumination light lamps were used and the yarn was left under the lights for 1 and 5 minutes and also more minutes. The mechanism of photoluminescent sample is absorbing the light and storing the light energy during the charging process, and then illuminating. To measure the illumination property of the fabrics, a special box was prepared to provide the darkness. Prior to the exposure to light or activation, respectively, the samples were kept in complete darkness. Following to charging process with UV, TL84, D65 and F lights, the sample was taken and put into the dark chamber respectively (Figure 1). Intensity of the light emitting from the sample was reported. 4IN1 Multi-Function Environment Meter luxmeter was used to measure the intensity of the light. The distance between the sample and the measuring machine was 15 cm. Similar measurements were also done on the yarn. The yarn was evenly wound on a white cardboard carrier of 2 x 2 cm in size and activated for 5 minutes with all light types. Three measurements were done for each analysed parameters such as charging time, light source and sample form type (yarn and fabric). All measurements were carried out at room temperature.

In the last type of experiment, we studied the effect of different processes such as washing, rubbing on illuminating property of the fabrics. During the usage, textile fabrics can be exposed to friction and surface of the fabrics can be damaged causing the changes in illuminating ability. In this study, to simulate the effect of friction on luminescence, pilling test was done and the fabric was mounted both in the holder of Nu-Martindale Abrasion Tester and on the base plate so that it was rubbed against itself. After a certain cycle (15000 cycles), the fabric was taken from the holder and luminescence after activation of the fabrics was evaluated. Additionally, pilling rate of the fabrics were also assessed and given a scale according to standard fabric photograph after each certain cycle according to TS EN ISO 12945-2 test method [9]. On the other hand, the fabrics were washed 5 and 10 times in the Wascator CLS washing machine at 40°C without detergent. And then the samples were dried and afterglowing of the fabrics was measured. Lastly, the effect of optical brightener on illumination was studied. In this part, firstly, an impregnation bath containing 0.75 g/L optical brightener, 0.25 g/L wetting agent and 0.01 g/L acetic acid was prepared and the water was added until the concentration became 250 g/L. pH was adjusted to 5. Application was realized on a sample padding machine. The samples were rinsed with cold water and dried at 130°C, 3 minutes. Particularly, the effect of any finishing processes, rubbing and washing on afterglowing had been documented before. Therefore, in this study, we aimed to study the effect of some of the parameters on illuminance.

(a)

(b)

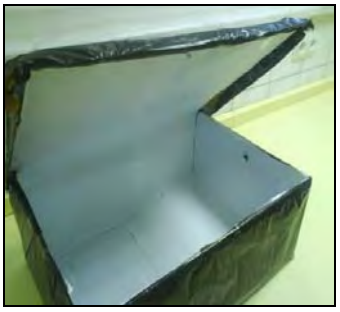

Figure 1. 4IN1 Multi-Function Environment Meter luxmeter (a) and measurement box (b).

3. RESULTS AND DISCUSSION

3.1. Yarn Appearance

Yarn appearances were analysed and typical views are shown in Figure 2.

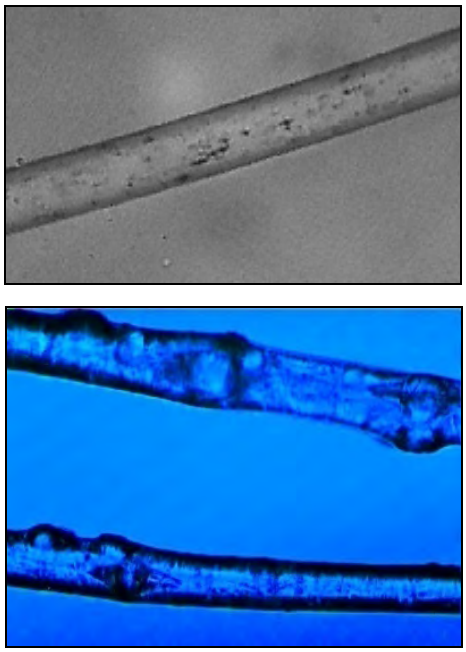

Figure 2. Yarn images of polyester (a) and photoluminescent fibre (b)

From the images, contrary to polyester yarn, it could be observed that luminous fibre does not have smooth surface. The diameter of luminescent fibre is not distributed uniformly along the fibre length. Suspended particles can be detected on the fibre surface and dispersed in the polyethylene terephthalate. In the study, chemical analysis was done to determine the material on fibre surface. The luminescent fibre was left in m-cresol (100%) at 90°C for 10 minutes according to AATCC Test Method 20-2002 [10]. As seen in Figure 3, the polyester fibre was solved completely. However, it was observed that transparent residue particles exist in solution and the particles could be seen with naked-eye (a) and also microscopy (b). As a result, luminous materials were clearly apparent on fibre surface.

As seen in Figure 3 (b), the luminescent grains were randomly distributed and they have irregular shapes with sharp edges. The size of the particles and also fibre diameter was measured by Image Plus BX 2. Particle size was about 20-60 µm and mean size was determined as 41.8 µm. On the other hand, the particles inside the fibre seemed to be un-uniform through the fibre length. The diameter became larger with rare earth luminescent materials and the thick places on the fibre were determined as 757.3 µm while thin places were 461.83 µm. Mean fibre fineness was evaluated as 609.56 µm. As a result, rare earth luminescent materials may lead to less evenly fibre diameter distribution. In literature, some of the researchers have also reported irregular particle distribution and fibre diameter [5-6]. They also stated that luminosity will be at a maximum when the rare earth aluminates complex is uniform in size and shape and distributed evenly within the fibre [6]. As in this work, unfortunately, luminescent particles lead to un-uniform fibre diameter distribution.

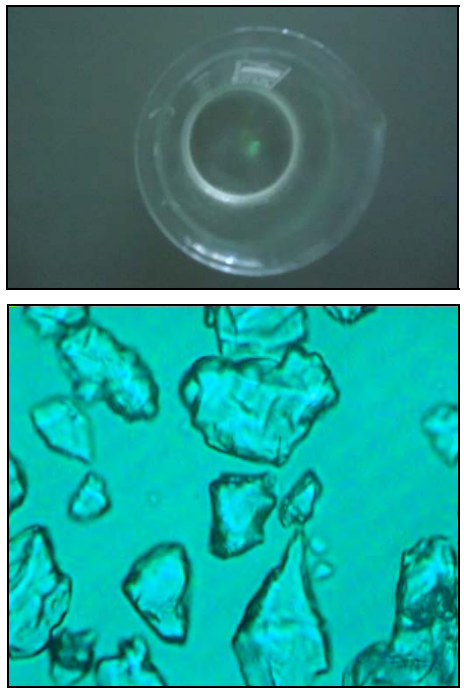

Figure 3. Luminous particles

3.2. Tensile Properties

Table 1 shows the breaking tenacity and elongation results of polyester and luminescent fibres. As seen, the breaking tenacity of polyester fibre is higher than that of luminescent fibre. The differences in strength values of the fibres were determined statistically significant and hence the luminescent polyester fibre has considerably lower fibre strength than polyester fibre. On the other hand, breaking elongation of luminescent polyester fibre is significantly higher than polyester fibre. Lower tenacity and higher elongation results of

the luminescent fibre were coincided with the literature [5-6]. Previous studies explained tensile properties of luminescent fibre with fibre crystallinity and orientation. It was reported that luminescent particles dispersed in luminescent fibre damaged the macromolecules crystalline area to some extent, resulting in lower fibre crystallinity [5-6]. This case may lead to lower resistance in luminescent fibre to break and stretch. On the other hand, standard deviation values of tenacity and elongation properties are considerably higher for luminescent fibres in comparison to that of the polyester fibres. This may result from un-uniform distribution of particle size and hence fibre diameter of luminescent fibres.

3.3. Pilling Behaviour

Table 2 displays the pilling rates of the knitted fabrics produced from luminescent fibres. As seen, any observable changes did not occur on the fabric surface and pilling rate was assessed as 5 which means no pilling. Even at higher cycles than 7000, there was not any pilling on the fabric. Therefore, luminescent fabrics display perfect resistance to pilling and friction could not cause remarkable damages on fibre surface.

3.4. Illuminating Property

3.4.1. The Effect of Light Source Type

The photoluminescent knitted fabrics were exposed under four different light sources for 5 minutes and luminous intensity of the fabrics was measured. UV, TL84, D65 and F light types were used for the activation. UV is ultraviolet lamp while TL84 is called as cool white. D65 symbolizes the daylight while F is yellow light [11]. After exposing the fabrics with the lights, luminance intensity of the fabrics was measured by luxmeter. The measurements were done at certain intervals, starting from 10 seconds to 30 minutes. The decay characteristics of photoluminescent fibres were investigated and indicated in Figure 4.

Table 1. Mechanical properties of the fibres

Values	Breaking tenacity (gf/denier)		Breaking elongation (%)	
	Luminescent fibre	Polyester fibre	Luminescent fibre	Polyester fibre
Average	1.91	02.78	36.82	22.95
Maximum	2.18	03.35	41.07	25.77
Minimum	0.71	02.34	13.67	19.09
Mean square deviation	0.34	00.27	07.91	02.00
Coefficient of variation (%)	17.80	09.69	21.49	08.72
Significance (<0.05)	0.00*		0.00*	

Table 2. Pilling resistance results of luminescent fibres

Cycles	125	500	2000	5000	6000	7000	10000	15000
Grade	5							

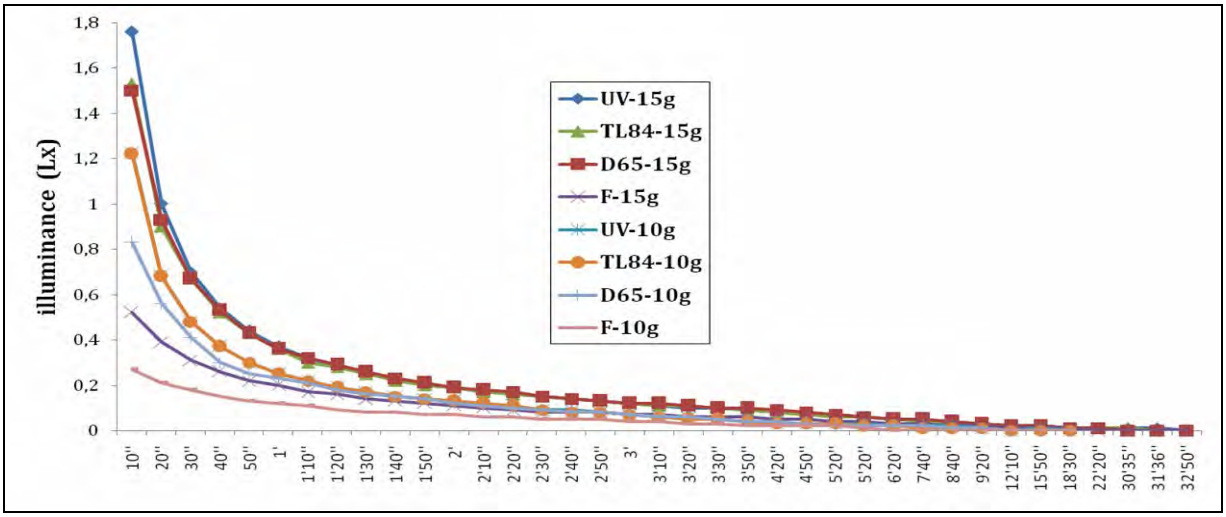

Figure 4. Decay curve of the luminous fiber at different exposing lights (15 g and 10 g fabric weights)

In the graph given in Figure 4, the axial axis shows decay time while the vertical axis demonstrates the luminance intensity. As seen, luminous intensity values of the samples change with the time. Luminance intensities after the excitation or the removal of the light sources decrease rapidly at the initial luminescence. Afterglow undergoes a rapid large reduction during the first minute. Then it was observed a long lasting decay of the afterglow and the speed of this period is slower than initial afterglow. Therefore, as mentioned in previous studies [5-6], luminance intensity curves of the photoluminescent fabrics display three-region structure. They are fast, medium and slow decay. The afterglow in fast decay is more intense than that of the luminous fibre during the medium and slow decay periods. In the study, the measurements were done on two different sample weights and both samples showed similar decay characteristics.

Luminescent materials such as rare-earth materials used for the fibre have an unfilled and external shielded 4f5d electronic configuration [5, 12]. Therefore, various energy levels, spectral terms and over 200,000 energy-level transition channels can be formed in the ion. The energy levels and spectral lines of the ions are far greater than common elements and can absorb or emit various wavelengths. The decay processes of samples were caused by different depths of trap level in materials. Under continuous illumination, the deeper energy levels have priority in receiving the excited electrons, which will be trapped by the slow energy levels until the deep defect energy levels have been filled by the excited electrons. After the luminous fibre has absorbed illumination for 5 minutes, the amount of electrons which are trapped by low and deep trap energy levels of the rare earth luminous material has already reached saturation. The low trap energy levels associate with the fast process of afterglow intensity decay, and the deep trap energy levels are related to the slow process [6]. Thus, during different times of excitation, the afterglow intensity of the luminous fibre presents a remarkable set of characteristics, as shown in Figure 4. During the initial decay period, the trap energy level was very shallow and an electron could readily escape from the trap, resulting in a rapid decay in afterglow.

When the luminous intensity values of the lights were compared, main difference was observed at initial intensity values. Particularly, when the initial intensity values after illumination for 10 seconds were compared, it was determined that intensity values obtained by UV light are the highest while F light provides the lowest afterglowing (Table 3). UV light provides three times higher luminescence intensity in comparison to F light. Even, in the sample with 10 g, the difference between UV and F lights reaches to six times. Following UV light, TL84 and D65 lights have almost similar luminous intensity values. After the initial illumination, the intensity values of UV, TL84 and D65 lights decrease significantly and reach almost similar level. Therefore, the curves of the three lights overlap. However, the afterglowing intensity of F lights is considerably lower than the other lights and so its curve does not overlap with other curves. Along the all decaying period, the samples charged with UV, TL84 and D65 lights have higher illuminance.

On the other hand, when the decaying times of the lights were compared, UV light enhances the longest afterglowing while F light provides the shortest illuminance. For UV light, luminous intensity decreases to zero after 32 minutes in 15 g and 24 minutes in 10 g (Table 3). However, in F light, luxmeter did not report any illumination value after the time reached 22 minutes for 15 g and 8 minutes for 10 g. As to TL84 and D65 lights, it was not observed an efficient luminescence after 30 minutes in 15 g and 16 minutes in 10g. Actually, TL84 and D65 lights give similar illumination. On the other hand, UV, TL84 and D65 light sources enhance longer afterglowing duration than the F light. In the meantime, it is also required to state that there was still slightly visible light after 22 minutes for F light and this case is also true for other lights. And a dying down of the light was not observed. The reason of this case may be that intensity of the light was not in the measurement range of the luxmeter. Meanwhile, as the fabric weight increased, higher initial illuminance and decaying time were obtained.

Table 3. Illuminating results

Sample weight (g)	Light source	Initial illumination at 10 sec (Lx)	Final illumination time (minute/second)
15	UV	1.760	32'50"
	TL84	1.530	31'36"
	D65	1.500	30'35"
	F	0.520	22'20"
10	UV	1.225	24'05"
	TL84	1.220	16'23"
	D65	0.830	16'21"
	F	0.270	08'40"

The differences in luminance characteristics of different lights may be due to the luminescent features and different colour temperatures of the lights. Prior to the activation of the fabric samples, luminescent intensity of the lights emitting from the each lamp was measured by luxmeter and the results were given in Table 4. As seen in Table 4, UV and TL84 light sources have higher intensity values, and thus higher illumination and long-lasting afterglowing were obtained when the knitted luminous samples were activated with UV and TL84 lights. On the other hand, luminous intensity values of D65 and F light sources (2600 lux and 2700 lux) are considerably lower than that of the UV and TL84 lights (Table 4). However, colour temperature of D65 light is 6500°K [11, 13] and considerably high temperature may be primarily reason for its higher illumination and long-lasting afterglowing properties of D65 light. Colour temperature describes the colour appearance of the lamp itself and the light which is emitted can vary along with its spectral power distribution. Colour temperature is one of the ratings which are commonly used to describe the colour properties of lamps. On the other hand, F light has considerably lower colour temperature (2300-2800°K) and luminescent intensity values. Hence, F light source leads to lower luminescence and long-lasting afterglowing. Shortly, UV, TL84 and then D65 light source may produce more energy and electron activity and thus enhance better afterglowing properties.

Table 4. Characteristics of the activation lights

Light source	Luminescent intensity (cd/m^2 (Lx))	Colour temperature (°K)
UV	3500	-
TL84	3600	4000
D65	2600	6500
F	2700	2300-2800

3.4.2. The Effect of Activation Time

In this part of the study, the fabrics with 15 g were waited under the four different light sources at 1 and 5 minutes. Luminance intensity of the fabrics was measured by luxmeter after the illumination. Initial luminescent intensity is given in Figure 5.

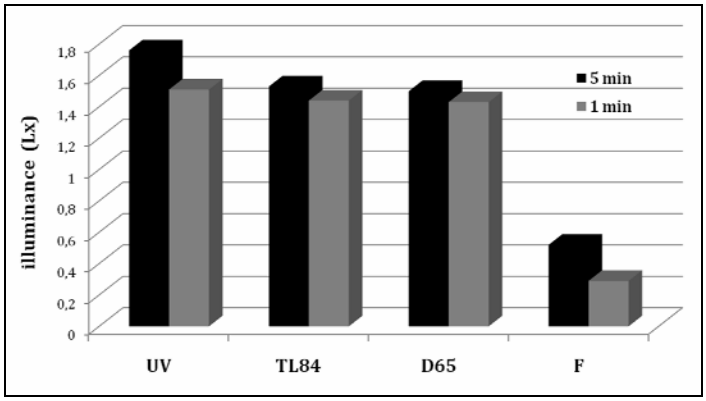

Figure 5. Initial luminance intensity results of all the lights after 10 seconds

As seen in Figure 5, luminous intensity values obtained by UV lights are the highest while F lights enhance the lowest afterglowing at both activation times. The differences in luminance between F and UV lights almost reached to three times. On the other hand, initial luminance intensity of all the samples increase with long-lasting activation. Particularly, intensity values of F lights increase up to two times with 5 minutes activation. However, in other light types, longer activation did not lead to remarkable increase in luminous intensity values while the decaying times of the samples improve with longer activation. But, the amount of improvement in long-lasting activated with UV, D65 and TL84 is about 2-3 minutes. As to F light, illumination was greatly increased up to 20 minutes (Table 5). The highest increase was observed in F light.

Table 5. The effect of activation time of illumination characteristics

Light source	Initial illumination at 10 sec (Lx)		Final illumination time (minute/second)	
	5 min	1 min	5 min	1 min
UV	1.76	1.51	32'50"	32'40"
TL84	1.53	1.44	31'36"	29'30"
D65	1.50	1.43	30'35"	27'20"
F	0.52	0.29	22'20"	03'40"

The luminous intensity was greatly increased with the activation by UV, TL84 and D65 lights for 1 minute. But, intensity became more or less constant after 1 minute. Hence, luminous intensity of the samples was seen to change only slightly with longer activation time (5 minutes). The initial luminous intensity almost reached saturation when the luminous fibre was exposed to illumination for 1 minute. Therefore, longer activation makes no sense to increase the afterglowing. Meanwhile, the light intensity also increased as the illumination intensity of the lights increased. But the time for the luminous intensity to reach saturation decreased. This was due to the fact that a source of high illumination intensity provides more energy, and the time for the luminous intensity to reach saturation decreases as the illumination intensity increases. This may be an explanation for incidental change of intensity and decay time of UV, TL84 and D65 lights after 1 minute activation. The samples charged with F light require relatively long build-up time to reach the saturated luminance level. Therefore, there is considerably increase in initial luminous intensity and decaying time values of F lights with 5 minutes activation. Nevertheless, longer activation than 5 minutes did not lead to any more change in illumination and afterglowing characteristics displayed consistency. These results coincide with the findings of Yan et al. (2012) [6].

3.4.3. The Effect of Sample Form

In the study, luminescent yarn was evenly wound on a white cardboard carrier of 2 x 2 cm and thus yarn samples have similar size with the fabric samples. The samples were activated for 5 minutes with all light types. The results are given in Figure 6.

As seen in Figure 6, the yarn samples display similar afterlowing characteristics and the three-region afterglowing decay was observed due to different levels of electronic trapping in the luminous material. As similar to fabric samples, F light provides the lowest illumination of all lights. UV, TL84 and D65 light sources almost give similar afterglowing. On the other hand, initial illumination values of the yarns samples are about 0.14-0.34 lx (Table 6). But, initial values of the fabric samples activated with UV, TL84 and D65 lights exceed 1.5 lx. The differences in initial illumination values of the fabric and yarn samples almost reach to five times although fabric and yarn samples occupy similar area. Additionally, fabric samples provide longer afterglowing than the yarn samples. The main reason may be the amount of luminescent material in the sample. This result was observed in fabric samples having different weights.

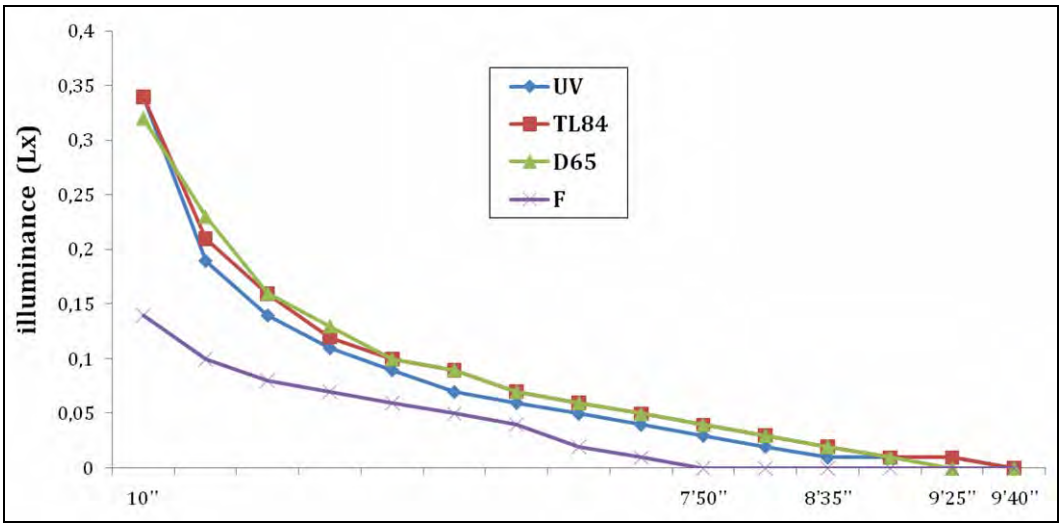

Figure 6. Decay curves of the yarn samples at different exposing lights

Table 6. Illumination characteristics of the yarn samples

Light source	Initial illumination at 10 sec (Lx)	Final illumination time (minute/second)
UV	0.34	09'40"
TL84	0.34	09'40"
D65	0.32	09'25"
F	0.14	07'50"

3.4.4. The Effect of Optical Bleaching

We aimed to analyse the effect of finishing process on illumination and to determine a positive effect of bleaching on afterglowing intensity. The fabric samples with 15 g were treated with the optical brightener and exposed to UV light for 1 and 5 minute. The results are indicated in Figure 7 and Table 7.

On the basis of the luminance measurements of untreated and treated samples after 1 and 5 minutes excitation, it can be observed that optical bleaching process increase luminance intensity slightly. However, bleaching did not cause any change in decaying character of all the samples. Meanwhile, bleaching process improve the decaying time of the samples.

Table 7. Illumination characteristics of the samples

Sample	Initial illumination at 10 sec (Lx)		Final illumination time (minute/second)	
	1 min	5 min	1 min	5 min
Untreated	1.51	1.76	31'50"	32'50"
Treated	1.55	1.80	32'44"	33'56"

3.5. Luminescent Materials Durability

3.5.1. Friction Resistance

In the study, the effect of abrasion occurred during textile processes and daily usage was studied. The fabric samples were rubbed to each other and then activated with UV light for 5 minutes after 500, 3000 and 15000 cycles. Figure 8 and Table 8 present illumination results of un-rubbed and rubbed samples.

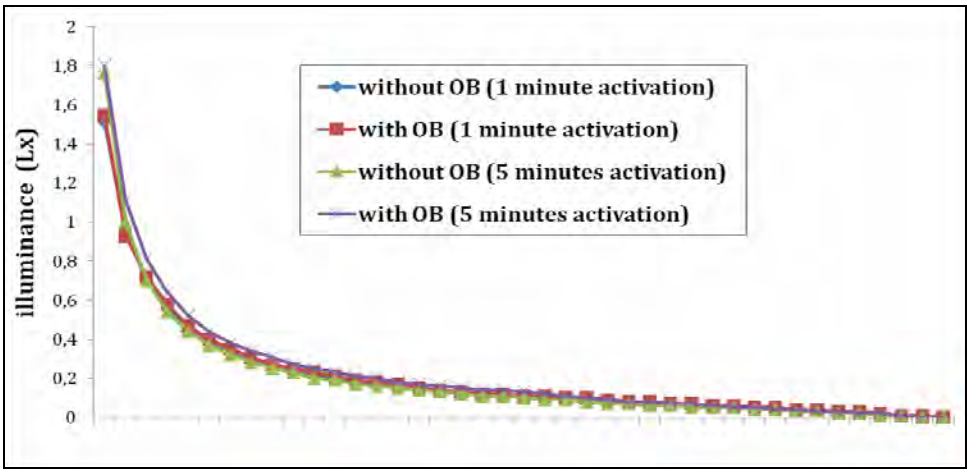

Figure 7. Decay curves of the treated and untreated fabric samples

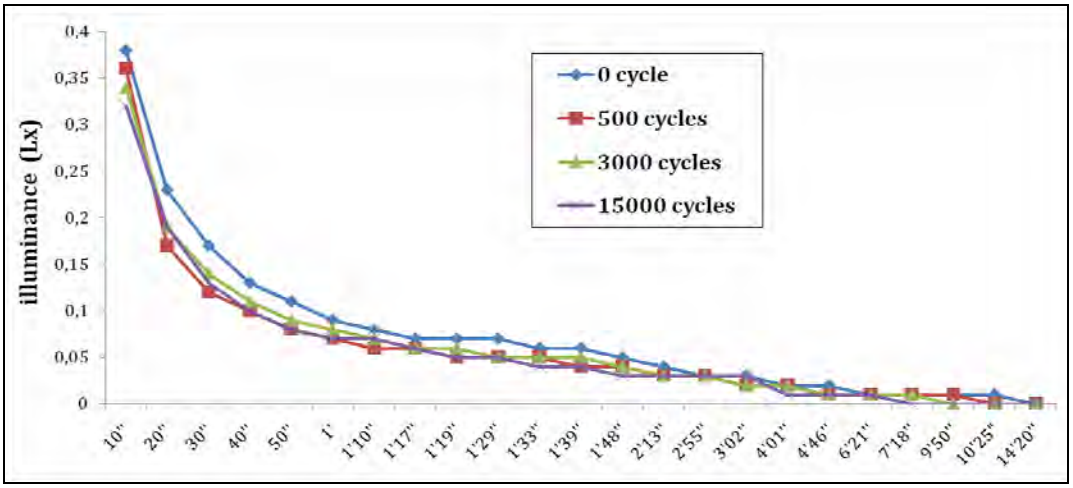

Figure 8. Decay curves of the un-rubbed and rubbed samples

In Figure 8, similar decay curves were observed in un-rubbed and rubbed fabric samples knitted from luminescent fibres. Rubbing effect caused slightly lower luminance intensity values (Table 8). The amount of decrease in initial illumination values may not be taken into consideration. However, a relatively high decrease became in decaying time, and afterglowing lowered about half of time after 15000 cycles in comparison to un-rubbed sample. The primarily reason may be damages on fibre surface and abrasion is getting more as the friction increases.

3.5.2. Washing Resistance

In this part, the resistance of afterglowing property of luminescent fibre to washing was evaluated. Luminance and the changes in luminance with time were measured for unwashed and several times washed samples. The fabrics were exposed to UV light at 5 minutes after washing. The results are summarized in Table 9 and indicated in Figure 9.

Afterglowing profiles of un-washed and several times washed fabric samples overlap with each other and display three-region structure of fast, medium and slow decay. On the other hand, the initial illuminance and lifetime of the afterglow remained similar after several times washing. Luminous intensity and decay time was seen to change only slightly with washing. Hence, luminescent fibres are considerably resistant to washing.

Table 8. Illumination characteristics of the un-rubbed and rubbed samples

Sample	Initial illumination at 10 sec (Lx)	Final illumination time (minute/second)
Un-rubbed (0 cycle)	0.38	14'20"
After 500 cycles	0.36	10'25"
After 3000 cycles	0.34	09'50"
After 15000 cycles	0.32	07'18"

Table 9. Illumination characteristics of the un-rubbed and rubbed samples

Sample	Initial illumination at 10 sec (Lx)	Final illumination time (minute/second)
Un-washed	1.22	26'05"
After 5 times washing	1.17	25'50"
After 10 times washing	1.11	24'39"

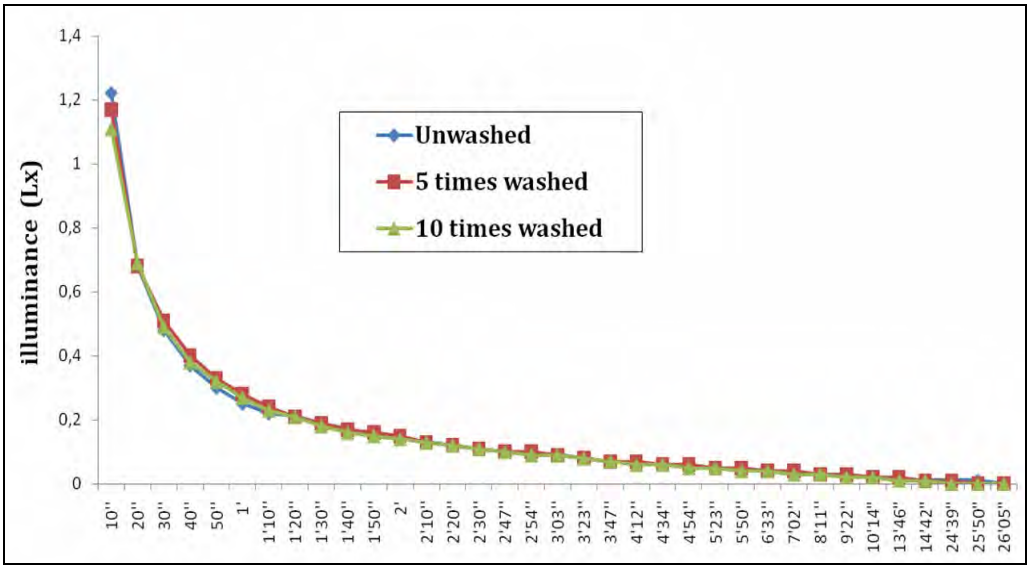

Figure 9. Decay curves of the un-washed and several times washed samples

3.6. Effect Level Analysis of Analysed Parameters

In this part, we adopted average level analysis to interpret the effect of analysed parameters on illumination intensity and decaying time. In this analysis, we followed the method mentioned in one of the work realized by Cheng and Li (2002). According to this analysis, it was aimed to calculate the difference between the highest and lowest luminance results of the samples activated with UV light for each parameters which was studied in this work. And each difference value was accepted as a measure of the strength for the concerned parameter. As the difference is getting higher, the value means that the parameter has the strongest effect on afterglowing. The results of effect level analysis are given in Table 10.

According to Table 10, sample form, light source type and then sample weight have the strongest effect on afterglowing. When samples are activated with UV light and sample weight is increased, higher initial luminance intensity values and long lasting afterglowing can be obtained. On the other hand, optical bleaching process lead to a positive effect on luminance while rubbing lowers illumination. Particularly, afterglowing feature of luminescent fibres are getting worse as the friction increases above 15000 cycles. On the other hand, washing did not cause a remarkable decrease in illumination.

4. CONCLUSIONS

Present study investigated the illumination characteristics of luminescent fibre and also the effects of the some parameters on decay characteristics. In the work, it was determined that luminescent materials may lead to unsmooth fibre surface and less evenly fibre diameter distribution. Meanwhile, luminescent particles dispersed in the fibre structure damage the macromolecule crystallinity and this case result with lower fibre strength and higher breaking elongation values. Luminance intensity of the fabrics knitted from luminescent fibres decrease rapidly at the initial luminescence and then long lasting afterglowing was observed. Therefore, illumination character of luminescent fibre was concluded as three-region decay structure of fast, medium and slow, and different depths of trap energy level in the materials is the primarily reason for variation in illumination character of the luminescent samples. On the other hand, UV and then TL84 and D65 light sources enhances the highest luminescent intensity values. Meanwhile, the fabrics provide illumination about 30 minutes after 5 minute activation with these lights. Even, visible light could be observed after 30 minutes. Luminous intensity and long-lasting afterglowing could be improved with higher charging time. However, longer activation did not lead to any more change in illumination due to saturation of the deep trap energy levels of the luminous material with the excited electrons. In this study, it was determined that 1 minute is almost enough for exposing the luminous samples and longer activation makes no sense to increase the afterglowing. Luminescent fabrics display perfect resistance to pilling, and friction could not cause remarkable damages on fibre surface. However, initial illumination intensity values and decaying time lowers as the rubbing cycles increases. Nevertheless, the reduction became as significant after 15000 cycles. On the other hand, multiple washing processes cause only slightly decrease in

Table 10. Effect level analysis results of the parameters

Parameters	Initial illumination at 10 sec (Lx)	Final illumination time (minute/second)
Light source (UV/F)	+1.24	+10'30"
Activation time (1/5 min)	+0.25	+00'10"
Sample weight (10/15 g)	+0.54	+08'45"
Sample form (yarn/fabric)	+1.42	+23'10"
Optical bleaching (untreated/treated)	+0.04	+01'56"
Friction (after 500 cycles)	-0.02	-03'95"
Washing process (after 5 times)	-0.05	-00'55"

luminous intensity and long-lasting afterglowing. Therefore, luminescent fibres are considerably resistant to the washing and rubbing effects occurred in daily usage or textile processes. Meanwhile, optical bleaching process improves luminance. When samples are activated with UV light and sample weight is increased, higher initial luminance intensity values and long lasting afterglowing can be obtained.

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