

**Photodegradation of the Holly Kaaba Cover Fabric  
by the Environmental Conditions in Mecca City**

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**ABSTRACT**

*Samples of the holly Kaaba jacquard silk cover fabric were exposed directly to the prevailing environmental conditions at Mecca city in the Kingdom of Saudi Arabia (KSA) through whole one year and at different successive periods. Thus, the incident solar energy (ISE) values and the accompanied amount of UV radiation were evaluated for the whole exposure periods, together with average maximum temperature and relative humidity values and also the total amount of sunny hours. The produced photofading was assessed by following the changes in the physical and mechanical properties. Thus, losses of tensile strength and elongation percent, together with the change in drape, stiffness, weight and the thickness were assessed and discussed. Moreover, the changes in the color parameters: brightness (L), red-green component (a), yellow-blue component (b) and the allover color difference ( $\Delta E$ ) changes, in addition to the color strength expressed as (k/s) values, besides the light fastness ratings were also examined. It was concluded that, the prevailing severe environmental conditions together with the air pollution at that urban site had contributed greatly to the observed degradation of all examined properties of the holly Kaaba silk cover fabric. Maximum losses were observed at summer time and during the pilgrim period.*

*Keywords: Environmental Conditions, Photodegradation, Kaaba, Silk fabric, Physical Properties*

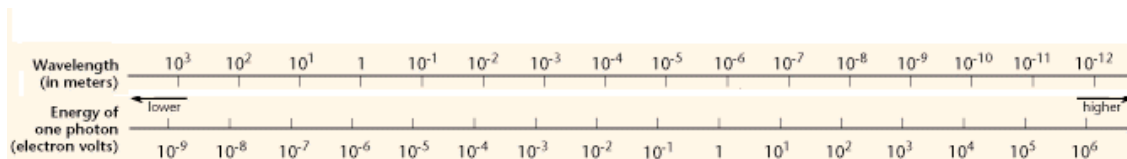
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**1. INTRODUCTION**

Photodegradation arise when light or other similar form of electromagnetic radiation to which the fibers are exposed brings about chemical damage changes in the molecular structure of the textile polymer. In order for this to take place; it is necessary for this radiation to have enough energy to bring about the change, usually by exciting some

part of the polymer molecules. Figure (1) shows the energy of electromagnetic radiation and their corresponding energy (ev). The excitation often causes a major change in the molecular structure of the polymer, which then leads to gradual loss of mechanical properties. The energy of the UV portion of the solar radiation corresponds to many important bond-dissociation energies [1-14].



**Fig. 1. Electromagnetic wavelengths and their equivalent energies [14]**

The term “Weather” refers to a complex system of many components for which there can be no actual standards. The features of weather most responsible for photodegradation are light particularly of near UV. of the range (290-315 nm), moisture in liquid or vapor form temperature, oxygen, ozone and pollutants [1], [3], [12], [15]-[19].

Exposure of high polymers to the environmental conditions i.e. weathering involves changes in the molecular structure that brings about changes in any physical or chemical properties. Thus, weathering of textile materials causes breakdown of molecular structure which in turn results in loss in strength, abrasion resistance, extension stability, general durability, discoloration, fading and possibly appearance and aesthetic characteristics,

In more recent years, sunlight weathering tests have come under suspicion. It has been concluded that the total radiation measurements are not indicative of the degradation which the samples have actually undergone [1],[14],[18],[19]. Moreover, fluctuations in the total energy do not resemble the cyclic strength losses noted for the year and even at a constant level of total incident radiation, degradation seems to proceed faster in summer than in winter. Indeed, it has been proved that ultraviolet radiation of the spectrum is much more damaging than visible or infrared ones and a relatively good correlation exists between the loss in the fiber strength e.g. the tensile strength and the amount of the UV radiation absorbed. Seasonal fluctuations which occur in the UV radiation reaching the earth’s surface being highest during the summer months and lowest during winter were

attributed to the cyclic seasonal variation of ozone formed from oxygen of the atmosphere by photochemical processes. The concentration of ozone in the atmosphere varies with the altitude, latitude and the season of the year; also, the local meteorological conditions as well as the time of the day affect the thickness of the ozone layer. The amount of UV in the atmosphere is also affected by scattering. Thus, changes in the UV radiation must be taken into account when relating the loss in fiber strength to the degree of sunlight exposure [3], [15], [16], [20].

The importance of this study was to examine the suitability of the silk fabric already in use for covering holly kaaba to withstand severe weathering conditions prevailing at Mecca site for a whole one year of direct exposure in relation to its mechanical, color and fastness properties.

## 2. MATERIALS AND METHODS

### 2.1 Fabric

Black thick jacquard silk fabric of (609.4 g/m<sup>2</sup>) used to cover the holy Kaaba, produced by "Fabric Production Factory" in Mecca city, Kingdom of Saudi Arabia, was used in this work.

### 2.2 Exposure conditions

Exposure Method: The samples were directly exposed to the environmental conditions at Mecca city according to the standard method [15, 20].

Exposure Times: the samples were exposed at different periods as follows:

- Monthly for the whole year starting from October 2009 and till September 2010.
- Two successive months (March and April) representing the most mild conditions according to the monthly – year report of the Atmosphere Information Center of Saudi Kingdom, general authority of meteorology and environment protection [20].
- Four months representing the summer season (May- August)
- Eight months starting from Jan – August
- Twelve months starting from October 2009- September. 2010.

### **2.3 Temperature and Relative Humidity (R.H.)**

The daily average maximum of each month for both temperature and R.H. were recorded, and hence, the monthly averages were obtained [20].

### **2.4 Sunny Hours and Incident Solar Energy (ISE) and the Accompanied UV Radiation**

The number of sunny hours/month for the whole year together with the ISE were recorded and the accompanied UV radiation content at (290-315 nm) were evaluated, and the average values were calculated for each exposure period. The weathering data were taken from the nearest meteorological station to the exposure site [20].

### **2.5 Physical and Mechanical Measurements.**

These measurements were performed on the examined fabric samples before and after each exposure periods according to the standard methods.

- a. Weight/m<sup>2</sup> [21], thickness [22], drape [20, 23], stiffness [20, 22]
- b. Tensile strength and elongation [23, 25]
- c. Color component (L,a,b and  $\Delta E$ ) [24]
- d. Color strength expressed as K/S [26]
- e. Light fastness[24,26]

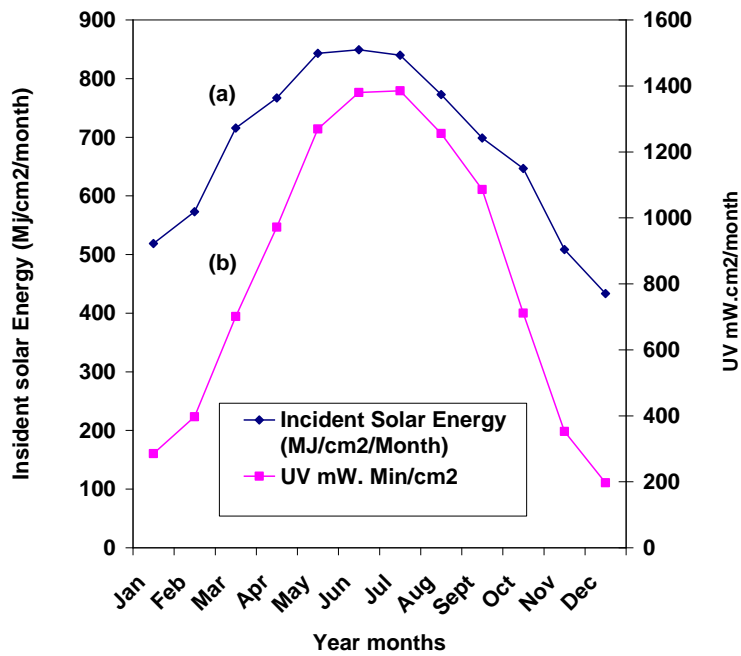
## **3. RESULTS AND DISCUSSIONS**

### **3.1 Environmental conditions**

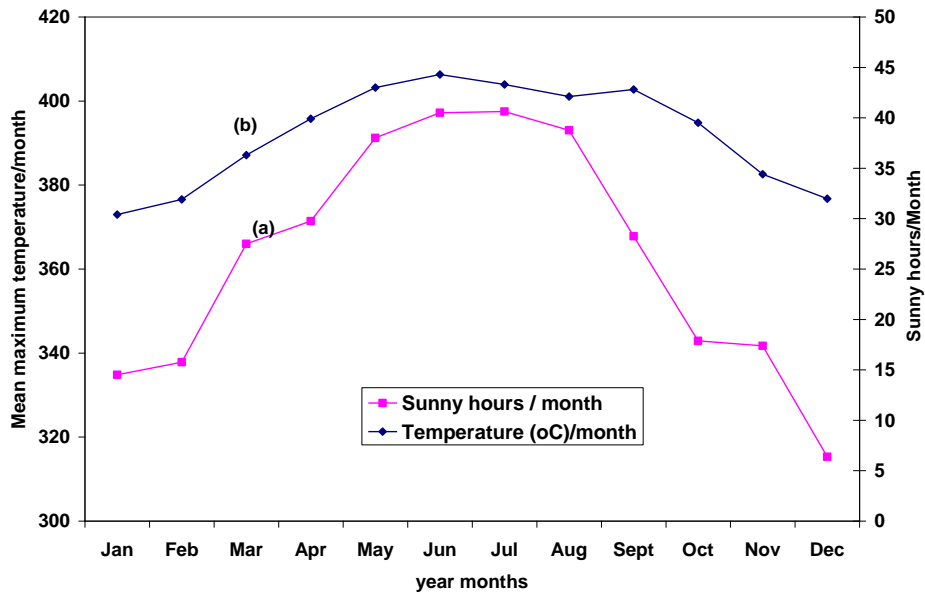
The monthly Incident Solar Radiation Energy ISE evaluated according to World Radiation Reference in (MJ/m<sup>2</sup>) are shown in Fig. (2) curve (a) where a cyclic variation is observed having a maximum in June and July and a minimum in January and December. Also, the monthly levels of UV radiation in mW.min/cm<sup>2</sup> at the range (290-315 nm) were estimated from the ISE data and are represented in Fig. (2) curve (b) where a similar curve is obtained with maximum in summer time and minimum in winter time. Also a similar cyclic variation was obtained when the mean of daily maximum temperature, also the numbers of daily sunny hours/month were represented against the year months in Fig. (3) curves (a and b), while Fig. (4) shows the mean maximum relative humidity/monthly relative humidity having a minimum value in June. Table (1) gives the environmental data of Mecca city during the chosen continuous exposure periods.

**Table 1. variation of the environmental data during the chosen exposure periods**

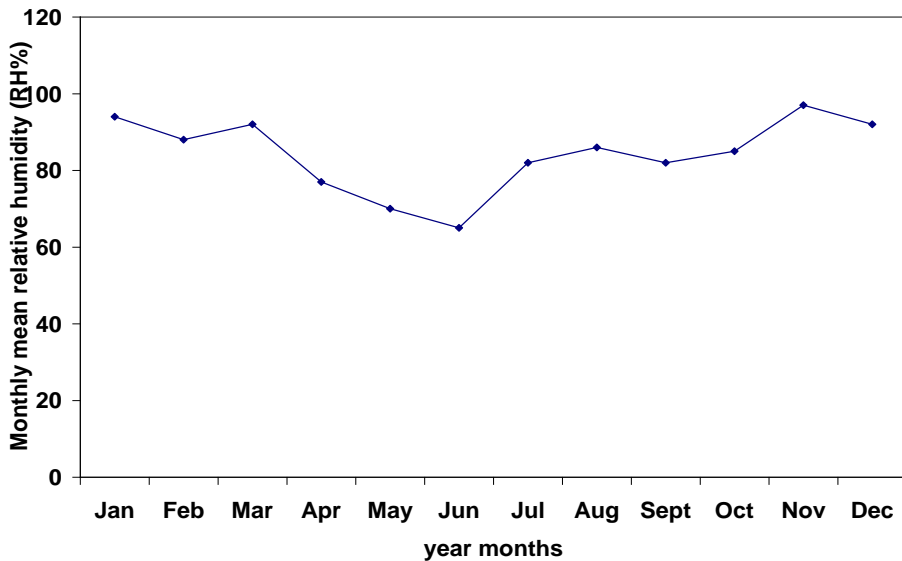
Exposure periods	Mean Max Temp.(°C)	Mean Max Relative Humidity (RH%)	Sunny hours	Incident Solar Energy (MJ/cm <sup>2</sup> /month)	UV mW. Min/cm <sup>2</sup>
1 month (June)	44.3	65	39712	849.0	1379.8
2 months (Mar & Apr.)	38.1	85	737.4	1482.5	1672.7
4 months -Winter (Oct-Jan)	34	92	1334.1	2106.8	1545.1
4 months Summer (May-Aug)	43.2	76	1578.9	3304.2	5289.3
8 months (Jan-Aug)	44.3	82	2988.3	5878.2	7644.1
12 months (Oct 2009-Sept 2010)	38.9	84	4356	816.5	9989.4



**Figure 2. Monthly Incident Solar Energy (ISE) and estimated UV radiation values during the exposure year**



**Figure 3. Mean average values of monthly maximum temperature and sunny hour values of Mecca City during the exposure year**



**Figure 4. Mean average values of maximum monthly relative humidity of Mecca City during the exposure year**

Considering the results of Figures 2 and 4, it was concluded that Mecca city is characterized by a severe weathering conditions, since it is located near the latitude (19-21) north. The sun rays fall perpendicular to Saudi Kingdom especially in summer time leading to high temperature

values and long sunny hours throughout the whole day and also, high ISE and UV values. The average maximum temperature values are very high in comparison with any other place in the world (29.1-34.3°C) for the hours of the day in winter time, and (39.9-43.3°C) in summer day times which

extended for seven months of the year. The average maximum values of monthly relative (RH) ranges between (65.0- 97%), while the mean monthly numbers of the sunny hours are (10.48-13.28). ISE ranges between 433.2-849.0 MJ/cm<sup>2</sup>/month while, the estimated accompanied falling UV radiation ranges between (196.7-1379.8) mW/min/cm<sup>2</sup>/month.

### 3.2 Effect of environmental conditions on physical and mechanical properties

Photodegradation of the Kaaba cover silk fabric was assessed by the changes in the physical and mechanical properties of the examined samples. The produced deterioration arising from weathering represented as variation of the samples weight/m<sup>2</sup>, thickness, drape, stiffness, tensile strength and elongation % are shown in Table (2). By analyzing these results it was concluded that all of these properties had been affected by such exposure but at different rates and ranges.

Both the weight/m<sup>2</sup> and the thickness of the examined samples were decreased gradually by small amounts after the different exposure periods. This low decrement was attributed to their high initial weight and thickness values. Moreover the outer layer of the fabric protected the inner ones. On the other hand, the samples' drape values were increased slowly with low rate indicating that draping property of the samples had diminished in spite of decrement of weight that calls for improvement in draping. This may be explained when considering the observed increase in stiffness values indicating that the samples became more stiff after the different exposure times causing increment of drape values.

The results of stiffness were also clearly reflected on the strength and extension of the fabric samples where considerable drop was observed in both properties. The tensile strength decreased from (325 to only 59 kg.f) after the whole exposing year, while the elongation % changed from (30.5% to 14%) through the same period.

**Table 2. Variation of the sample weight, thickness, drape, stiffness, strength and elongation % with the corresponding value of ISE and UV radiation after exposed periods**

Time of Exposure	UV (mW/min/cm <sup>2</sup> )	ISE (Langley)	Weight (g/m <sup>2</sup> )	Thickness (mm. X 10 <sup>-2</sup> )	Drape (mm)	Stiffness (g.cm)	Tens. St. (kg.f)	Elong. (%)
Unexposed (Control)	--	--	609.4	68.9	31.6	1.923	325±0.1	30.5±0.4
Two months March-April	1672.7	36043.8	586.9	66.6	32.0	1.923	175±1.4	22.0±0.2
Four Months May-Aug.	5289.3	78.969.6	574.4	65.4	34.3	2.318	159±0.6	17.5±0.1
Eight Months Jan-Aug.	7844.1	115049.8	560.6	64.0	36.3	2.681	89.0±3.6	16.0±0.4
Twelve Months Jan – Dec	9989.4	169706.4	553.1	63.2	37.8	2.987	59.3±2.0	14.5±0.2

Considering the percentage loss values produced to the Kaabah silk fabric samples arising by exposure to environmental conditions, which are given in Table (3), it was concluded that the % loss values of both the weight and thickness are relatively small ranging (3.7-9.2) and (3.3-8.3), i.e. these

properties were not seriously changed by such exposure even after the whole year. The draping of the samples, showed gradual small loss after the two mild months of exposure, and also after the summer four months. As the exposure proceeded the samples became stiffer and harder, hence

loss in draping increased reaching 21.5% after one year. The increase in stiffness values was not affected after the first exposure period, but after four summer months, the loss values were noticeably increased reaching a maximum (55.3%) after one year.

Although the weight and thickness of the exposed samples were not affected significantly by such exposure, but the results of the strength assured that the samples suffered considerably, they lost (46.2%) of their initial strength after the first two mild months, and continued losing strength reaching a maximum (81.8%) after one year. This means that dissociation had occurred to the chains of the fabric structure, beside increment in stiffness, leading to considerable decrement in strength and in elongation %, which recorded a loss of about (59.5%) after one year exposure.

The observed degradation in all examined properties may be attributed to the high values of temperature, RH, ISE, UV radiation and also to the high pollution occurring at Mecca site due to the increasing industrial and urban activities, and the rising in population density. Also, due to the huge amount of fuel usage either for domestic, industrial or transportation purposes,

especially during pilgrim or more times (2-3 million visitors), which release enormous amounts of gasses as a result of the incomplete fuel combustion along the whole days of the year. The geographical location of Mecca city is surrounded by mountains causing the presence of layer of gas pollutants and vapors over it all the time causing high weather pollution and rise of temperature.

The pronounced loss in the tensile strength of the examined fabric samples, in spite of their high weight values and compact weaving structure, besides their shape, may be attributed to the high amount of ISE absorbed by them and in turn high UV values. Also, their black color greatly enhanced the radiation absorbance.

Table (3) represents the % loss of tensile strength and elongation % against the ISE and UV radiation. Statistical study of tensile strength, elongation % losses, incident solar energy and estimated UV radiation showed a strong correlation to exist between the mention losses and UV than that of ISE. Their correlation factors were 0.961237 and 0.951989 respectively with a confidence of 95% for tensile strength loss% while for elongation % were 0.984069 and 0.945937 respectively.

**Table 3. Variation of the % change of weight, thickness, drape, stiffness, tensile strength and elongation % with the corresponding value of ISE and UV radiation of the exposed periods**

Time of Exposure	UV (mW/min/cm <sup>2</sup> )	ISE (Langley)	Weight (g/m <sup>2</sup> )	Thickness (mm. X 10 <sup>-2</sup> )	Drape (mm)	Stiffness (g.cm)	Tens. St. (kg.f)	Elong. (%)
Two months March-April	1672.7	36043.8	3.7	3.3	-1.27	0.0	46.2	27.9
Four Months May-Aug.	5289.3	78.969.6	5.7	5.1	-2.54	20.54	51.1	42.6
Eight Months Jan-Aug.	7844.1	115049.8	8.0	7.1	-14.87	39.42	72.6	47.3
Twelve Months Jan – Dec	9989.4	169706.4	9.2	8.3	-21.50	55.33	81.8	52.5

### 3.4 Exposure Effect on the Color Parameters

The photodegradation of the examined holly Kaaba black silk fabric samples was also assessed by spectrophotometric measurements via following the produced change in the color strength (K/S) values of the exposed samples; (2) color components (L,a, b and dE) and also the light fastness (LF). Table (4) shows the color data before and after the different exposure periods together with LF values. The obtained results showed that the (K/S) of these samples is considerably high i.e., examined fabric was dyed at very high dye concentration, and that the (K/S) values were decreased appreciably by exposure especially after the summer time and the long exposure times, assuring the stability of black dye. The obtained results of the color parameters proved that the used dye contained traces of red and blue colors. The portion faded by light after the different exposure periods, i.e., the values of 'a' was decreased. While, the blue parameter '-b' was increased i.e., the blackness of the

sample decreased appreciably after exposure periods and this was confirmed by the increment of lightness or the brightness of the black samples represented by component 'L' was increased by prolonging the exposure duration. The overall color change 'ΔE' showed an increase by exposure time. The recorded color results showed that the produced changes did not proceed in consistent with the exposure time especially after the whole year. The accumulated air pollutants particulates over the sample surfaces - as they were directly exposed to the environmental conditions- such as sand, dust, bacteria, pollen and other particles contributed greatly to such discrepancies of sample's color.

Concerning the light fastness 'LF' of the examined samples, the obtained results assured high stability of the black color of Kaaba fabric. The assessed light fastness values were (7/8) after exposure in June or to the two mild months, and (6/7) for the other different exposure periods. The 'LF' values are considered excellent-very good fastness ratings.

**Table 4. Variation of the color parameters L,a,b and ΔE, the color strength (k/s) and the light fastness (LF) with the exposure periods**

Exposure period	(L)	(a)	(-b)	ΔE	K/S	L.F
Unexposed (Control)	15.22	0.65	0.82	--	23.4032	--
June	15.43	0.45	0.72	0.14	23.1631	7/8
March-April	15.49	0.23	0.93	0.51	22.7143	7/8
May- August	15.41	0.35	1.00	0.89	22.4112	6/7
Jan- August	15.59	0.25	1.07	0.60	22.3842	6/7
Oct. -Sept.	15.22	0.41	-0.82	0.24	22.3921	6/7

### 4. CONCLUSIONS

The observed severe weathering conditions prevailing in Mecca city due to its geographical location and the surrounding mountains contribute to the high temperature, relative humidity, daily sunny hours, incident solar energy and near UV radiation. Besides, the presence of a huge amount of pollutant released gases in the atmosphere. This may be related to the increasing industrial, urban and

transportation activities. These factors contributed greatly to the increasing degradation of Kaaba cover fabric. All the examined physical and mechanical properties were affected by such exposure, where considerable losses in the tensile strength and elongation percent of the fabric samples were observed. Nevertheless, the fabric was left stiffer and less draping with small decrement in weight and thickness values. The kaaba's black cover fabric resist considerably the effect of the solar



radiations. It showed high color strength and very good light fastness ratings. Moreover the color parameters of the Kaaba fabric recorded appreciable changes in their values by such exposure. Stronger correlation was found to exist between losses percent of strength and elongation values with the UV radiation more than that with the incident solar energies. This means that, UV is the predominant factor affecting the photodegradation of the fabric sample by weathering. According to the obtained results it was concluded that, the black dye used for coloring Kaaba cover fabric is quite suitable in resisting the light and weathering effects. While the silk fabric needs more extensive work in relation to spinning and weaving techniques to improve its resistance to the weathering conditions.

## 5. ACKNOWLEDGMENT

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