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Photodegradation of an Anthraquinone Type Disperse Dye on Polyester, Diacetate, and Triacetate Fibers, and in Solution

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ABSTRACT

In a previous paper, the photodegradation behavior of an azo type disperse dye on polyester and nylon fibers was reported (Katsuda, N., Takagishi, T., Yabushita, S. & Hshizume, S., Dyes and Pigments, **31** (1996) 291). *In this present paper, the photodegradation behavior of an anthraquinone type disperse dye on fibers such as polyester, diacetate, and triacetate, and in particular on polyester fiber, and in solution have been investigated. The fiber itself and the dyed fiber were irradiated with monochromatic light of 20 different wavelengths from 201 to 701 nm, using as light source a Xenon lamp divided into 20 wavelength parts. The photodegradation behavior at each wavelength was examined to elucidate the mechanism of the photofading of the dye on the fibers. It was observed that the disperse dye on polyester fiber was significantly affected at around 316 nm. The same dye on diacetate and triacetate fibers underwent photofading near 230 and 259 nm, respectively. The fiber itself was influenced remarkably at the corresponding wavelength. To clarify these situations, the photodegradation of the dye in ethyl acetate containing dissolved polyester was checked. The dye was found to be degraded markedly at 316 nm also when polyester was present in the system.*

Keywords: photodegradation, wavelength, spectroirradiator, disperse dye, anthraquinone, fiber.

INTRODUCTION

Many studies have been made of the photodegradation of dyes on fibers.[2-22] However the mechanism of the photofading of dyes on fibers is not yet fully clear because there are many factors controlling the photofading. It seems pertinent, therefore, to separate these factors, and to derive the most important factors which are involved, and possibly hidden.

It is known that a dye shows different photofading behavior when the dye is adsorbed on different kinds of fiber substrate. In a previous paper, we described the photodegradation behavior of azo type dyes on polyester, nylon, and cotton fibers and in a solution.[1] In the investigation the photodegradation of the dyes on fibers and in solution was measured by using a monochromatic light source divided into 20 discrete wavelengths from 201 to 701 nm, instead of light involving the whole spectrum range. The photodegradation behavior at each wavelength was examined in order to simplify the system. It was found that both the azo type disperse dye on polyester fiber, and the fiber itself, were degraded simultaneously by light with the specific wavelength of 316 nm. Thus, the photodegradation of the dye on the fiber is largely dependent on that of the fiber itself. It is likely that the photodegradation of the dye on the fiber is significantly influenced by the absorbed energy which is characteristic of the fiber and/or the degradation products of the fiber formed at the specific wavelength.

In this investigation polyester, diacetate, and triacetate fibers, and an anthraquinone type disperse dye were employed, and the photodegradation of the dye on the fibers and in a solution was evaluated using the method as previously described.[1]

EXPERIMENTAL

Materials

Sumikaron Red E-FBL (CI Disperse Red 60, Sumitomo Chemical Co., Ltd) was used as a representative anthraquinone type disperse dye. Commercial grade dye was employed without further purification for the dyeing of polyester, diacetate, and triacetate fibers. Polyester (Tetron Tropical, Toray Co., Ltd), diacetate (Linda, Mitsubishi Rayon Co., Ltd), and triacetate (Soalon, Mitsubishi Rayon Co., Ltd) fibers were utilized after scouring. For dyeing polyester, diacetate, and triacetate, a commercial grade sample of anionic surfactant, Sumipon TF (Sumitomo Chemical Co., Ltd) was added. In order to elucidate the mechanism of the photodegradation in the polyester–disperse dye system, the photodegradation phenomena were investigated in solution. In this case, the dye purified by column chromatography was used. Ethyl acetate as solvent and polyester with a low molecular weight of about 10,000 were used.

Dyeing of polyester

The dyebath (180 ml) contained the disperse dye, anionic surfactant (0.2 g), and acetate buffer (0.2 g of sodium acetate and 0.05 g of acetic acid, pH 5). The dye concentration was calculated so as to correspond to a 1/1 shade (JIS). Polyester fiber (5 g) was immersed in the dyebath at 60°C and the temperature was raised from 60 to 130°C. Dyeing was continued for 30 min at 130°C, the temperature was then reduced to 60°C, and rinsing was carried out.

Dyeing of diacetate

Diacetate fiber was dyed by the same method as that of polyester fiber, but for this fiber dyeing was carried out at 85°C for 60 min.

Dyeing of triacetate

The method of dyeing triacetate fiber was essentially the same as that for polyester fiber. Triacetate fiber was dyed at 120°C for 10 min.

Apparatus

The spectroirradiator (CRM-FA, JASCO Co., Ltd) used in this investigation was the same as that used in a previous study,[1] in which an outline of the apparatus is presented. The light source was a Xenon lamp of 2 kW (UXL-2003D, Ushiodenki Co., Ltd). The lamp covers the wavelength region from 200 to 700 nm. The light was divided into 20 single wavelengths of 201, 230, 259, 288, 316, 344, 372, 399, 426, 453, 479, 505, 531, 556, 581, 606, 630, 654, 678, and 701 nm by a diffraction lattice. The fibers or cells mounted in the 20 sample rooms were irradiated by monochromatic light at each wavelength.

Measurements of photodegradation

The coloration, that is yellowing, of polyester, diacetate or triacetate fiber, and the color change of the dye on the fiber were evaluated by color difference data (ΔE) using a Macbeth Color-Eye 3000 (Sicomuc 20, Sumika Chemical Analysis Service Co., Ltd). The extent of photodegradation of the disperse dye in ethyl acetate was measured using a UV–Vis spectrophotometer (UVPC-3101, Shimadzu Co., Ltd).

RESULTS AND DISCUSSION

In an earlier study the photodegradation of azo type dyes on polyester, nylon, and cotton fibers was investigated using a spectroirradiator by which a monochromatic light source divided into 20 single wavelengths of 201, 230, 259, 288, 316, 344, 372, 399, 426, 453, 479, 505, 531, 556, 581, 606, 630, 654, 678, and 701 nm could be irradiated.[1] When polyester fiber dyed with CI Disperse Red 73 (an azo type disperse dye) was irradiated by monochromatic light of various wavelengths from 201 to 701 nm, the color of the fiber was changed by light of a specific wavelength. With polyester fiber, light of wavelength 316 nm showed the strongest power to degrade the dye on the fiber. It was also found that the polyester fiber itself significantly and specifically undergoes yellowing and degradation at 316 nm when the undyed fiber was irradiated with such monochromatic light. The same phenomena were observed in both nylon–azo type disperse dye and in cotton–azo type reactive dye systems. The fiber alone, and the dye on the fiber, were affected simultaneously by light of the same wavelength. With nylon, the wavelength of significant influence was 372 nm. In the case of cotton, the fiber alone and the fiber dyed with CI Reactive Red 195 (an azo type reactive dye) were influenced strongly by light at 259 nm. A similar situation was confirmed in a solution system in which dissolved polyester and CI Disperse Red 73 were present in ethyl acetate. In the absence of polyester in the solution, the dye was susceptible to light of shorter wavelength (i.e. of higher energy). In contrast, in the presence of polyester in the system, the dye tended to be decomposed maximally by light at 316 nm, at which wavelength of irradiation polyester undergoes significant photodegradation.

In this present paper, CI Disperse Red 60, a typical anthraquinone type disperse dye, was employed instead of the azo type disperse dye. The photodegradation of polyester, diacetate, and triacetate fibers was examined using the anthraquinone dye. The fiber itself and the fiber dyed with CI Disperse Red 60 were irradiated by the spectroirradiator used in the previous investigation.[1]

Figure 1 shows the qualitative photofading behavior of the three kinds of dyed fiber. Figure 1(A)–(C) represent the results for polyester, diacetate, and triacetate fibers, respectively. In Fig. 1, the regions illustrated by mesh and gradations demonstrate the fading parts and the extent of fading. The same anthraquinone disperse dye was used for the three fiber types. Nevertheless, the wavelengths affecting the dyed fibers differ with the type of fiber.

To clarify this situation, undyed polyester, diacetate, and triacetate were irradiated under the same conditions as those in Fig. 1. The results are shown in Fig. 2. Figure 2(A)–(C) show the appearance of the polyester, diacetate, and triacetate fibers, respectively. It was found that yellowing appeared at a specific wavelength. The lights and darks, i.e. the gradations, in Fig. 2 also illustrate the degree of this yellowing. It is likely that the yellowing implies photodegradation of the fiber itself and formation of degradation products of the fiber.

Focusing attention on the observed and qualitative results shown in Figs 1 and 2, the photodegradation of the undyed and dyed fibers was investigated quantitatively by measuring the color difference (ΔE) between the original and the irradiated fibers. The extent of fading of CI Disperse Red 60 on the polyester fiber and the yellowing of the undyed fiber are displayed in Fig. 3. The solid and dotted lines in Fig. 3 indicate the undyed and dyed polyester, respectively. As is apparent in Fig. 3, the dye on the fiber is degraded by light of wavelength 259–372 nm and is influenced maximally at 316 nm. The undyed polyester also shows the same trend. As has already been shown in the previous paper,[1] CI Disperse Red 73 (azo type) on polyester fiber was also affected most strongly at 316 nm. This result implies that the fiber causes

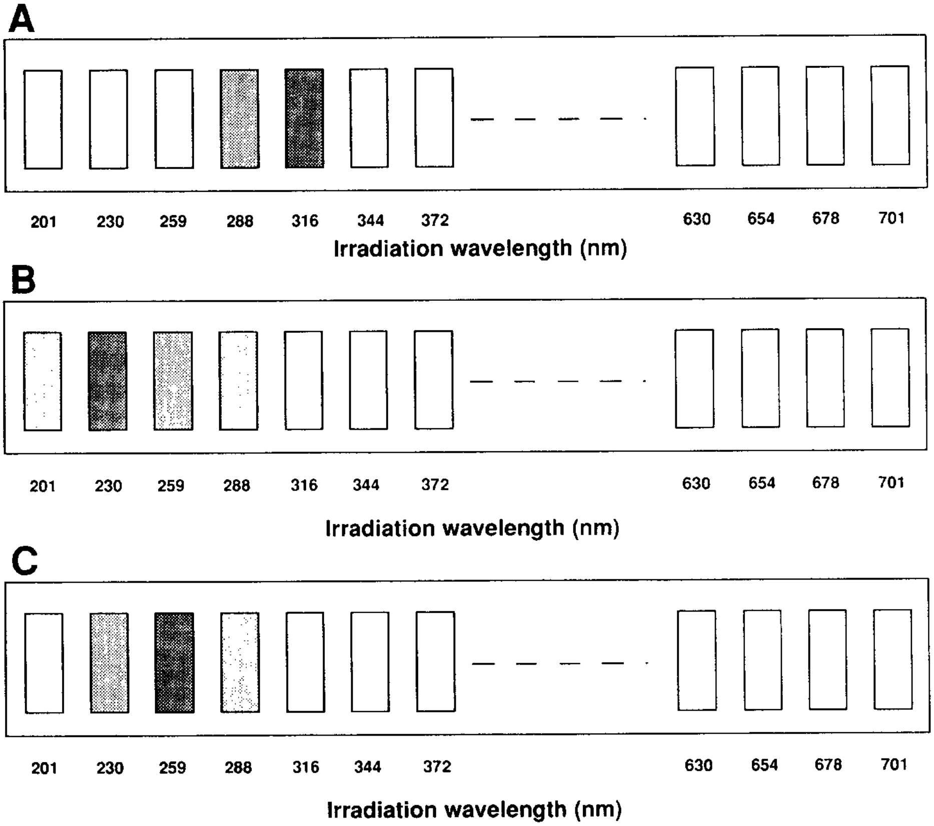

Fig. 1. Fading of dyed fiber by spectroirradiator: (A) fading of dyed polyester fiber; (B) fading of dyed diacetate fiber; (C) fading of dyed triacetate fiber. Irradiation energy 290 kJ/cm^2.

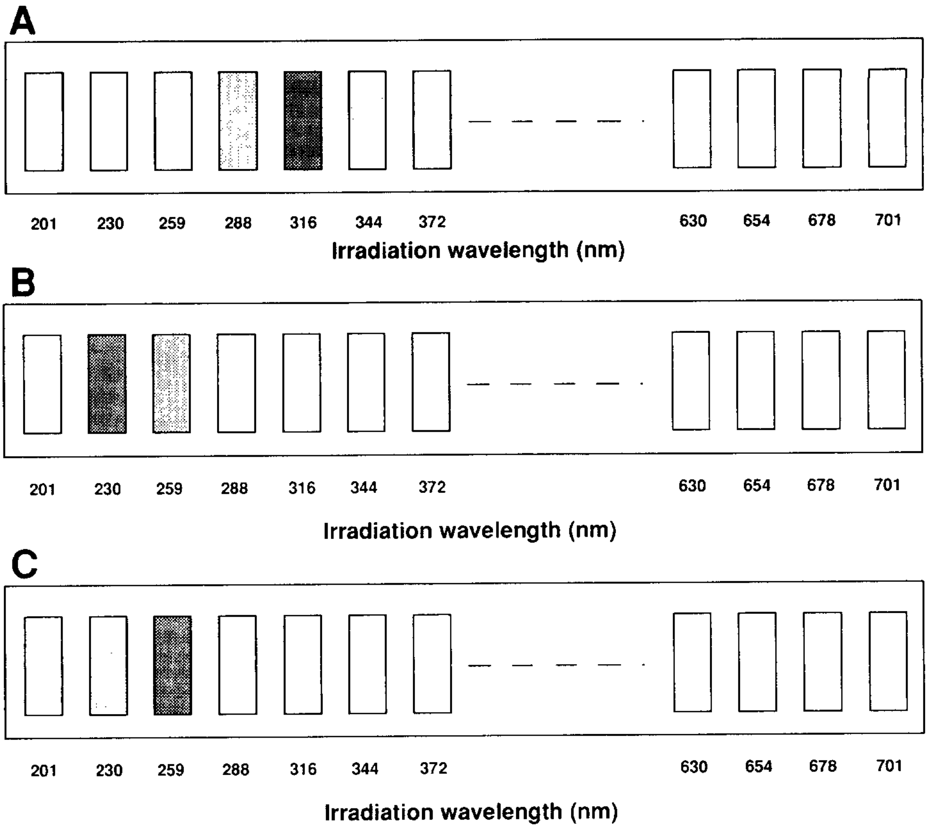

Fig. 2. Color change of undyed fiber by spectroirradiator: (A) color change of undyed polyester fiber; (B) color change of undyed diacetate fiber; (C) color change of undyed triacetate fiber. Irradiation energy 290 kJ/cm^2.

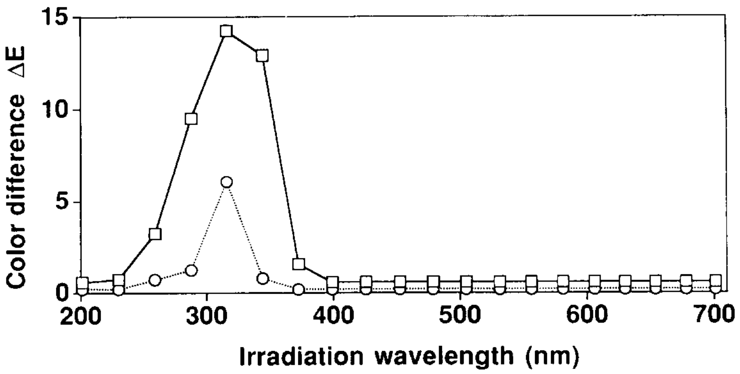

Fig. 3. Color change of undyed and dyed polyester fibers by spectroirradiation: (□) undyed polyester; (○) polyester dyed with CI Disperse Red 60.

photodegradation for the different dye structures (azo and anthraquinone), in the same manner, and that the photodegradation is independent of the structure of the dyes employed.

Figure 4 depicts the results for diacetate fiber; with this fiber both the dyed and undyed fibers are affected by light of wavelength 201–288 nm, the maximum effect arising at 230 nm. The results for triacetate fiber are also shown in Fig. 5. A similar trend to the polyester and diacetate fibers can be seen in Fig. 5, where both the dyed and undyed triacetate fibers are affected simultaneously at the same wavelength near 259 nm. The observations demonstrated in Figs 3–5 suggest that the fiber itself, and hence the degradation of the substrate, influence the photofading in a manner quite similar to that for the azo type disperse and reactive dyes reported in the study article.[1]

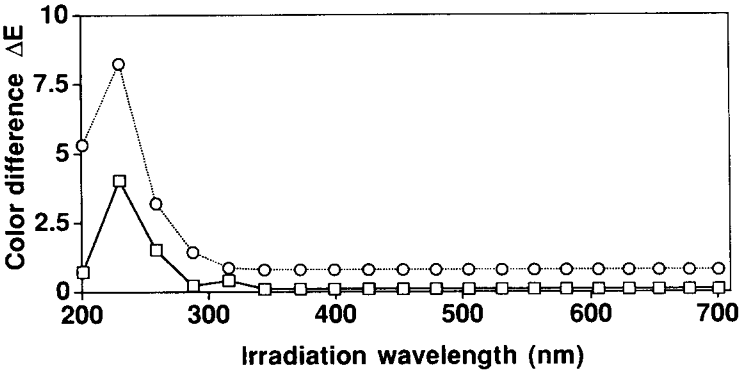

Fig. 4. Color change of undyed and dyed diacetate fibers by spectroirradiation: (□) undyed diacetate; (○) diacetate dyed with CI Disperse Red 60.

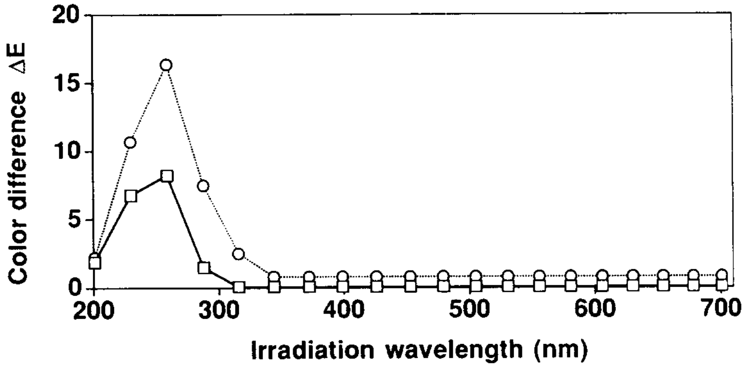

Fig. 5. Color change of undyed and dyed triacetate fibers by spectroirradiation: (□) undyed triacetate; (○) triacetate dyed with CI Disperse Red 60.

In order to confirm the above situation and to ascertain a more general rule for the photodegradation of dyes on fibers, the photofading behavior of CI Disperse Red 60 in solution was examined. For this purpose soluble polyester with a low molecular weight was used. Ethyl acetate was employed as a common solvent for the polyester and the disperse dye. Light of wavelengths at 288, 316, 344, and 372 nm was selected as the irradiation wavelengths because the fiber and the dye are influenced significantly at 288–372 nm, as already shown in Figs 1 and 2. Neither is affected at all above 372 nm and only slightly below 288 nm.

Figure 6 shows the photodegradation behavior of the disperse dye in ethyl acetate after spectroirradiation with light of four different wavelengths. In Fig. 6 the percentage of residual dye in the solution is plotted against the irradiation time. Figure 6(A) and (B) indicate the results in the absence and presence of polyester, respectively. As can be seen in Fig. 6(A), the percentage of residual dye decreases regularly with decreasing wavelength in the order 372 nm > 344 nm > 316 nm > 288 nm. This suggests that the dye in ethyl acetate is faded by light of shorter wavelength, since the shorter the wavelength, the larger is the energy. In contrast, Fig. 6(B) shows a decreasing percentage of residual dye in the following order: 372, 344, 288, 316 nm. The order at 316 and 288 nm is reversed compared to the result in the absence of polyester [Fig. 6(A)]. The results obtained in ethyl acetate are consistent with those observed for polyester fiber.

Data in Fig. 6 are rearranged in Fig. 7. Figure 7(A)–(D) show the photodegradation of the dye in the presence and absence of soluble polyester at 288, 316, 344, and 372 nm, respectively, for the purpose of a more simplified

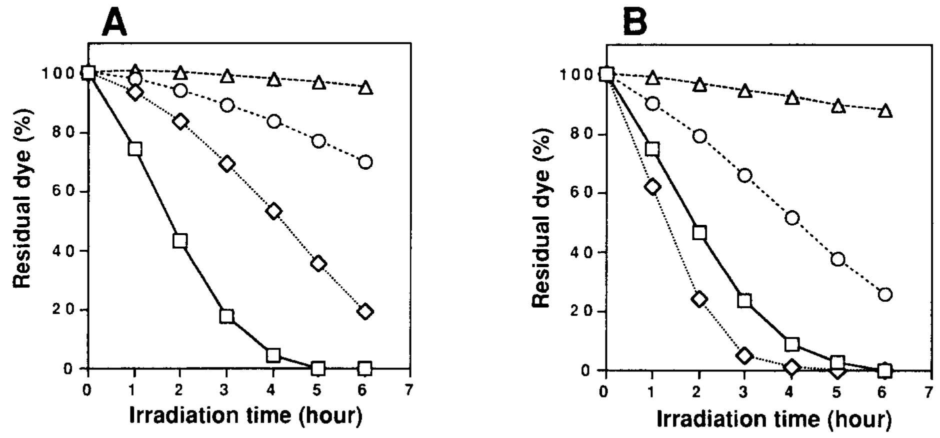

Fig. 6. Effect of irradiation wavelength on decomposition of CI Disperse Red 60 in ethyl acetate: (A) without polyester; (B) with polyester. (□) 288 nm, (◇) 316 nm, (○) 344 nm, (△) 372 nm.

and clearer expression. As is apparent in Fig. 7(A) and (B), at 288 and 372 nm the two curves in the presence and absence of polyester show a similar profile of photodegradation, irrespective of the presence of polyester, and the difference of residual dye in the presence and absence of polyester is negligibly small, indicating that the polyester involved in the system does not exert any effect on the photodegradation of the dye. However, at 316 and 344 nm, and in particular at 316 nm, the difference in residual dye between the two curves is very pronounced. The photofading of the dye becomes considerably faster.

From these observations it is very likely that fiber substrates and their photodegradation play a significant role in the photofading of dyes on the substrates. Thus the energy absorbed by the substrate at a specific wavelength might transfer to the dye molecules and induce photodegradation of the dye. Another possibility is that the degradation products of the fiber substrate formed by the absorbed energy characteristic of the fiber may attack the dye molecules present in the matrix.

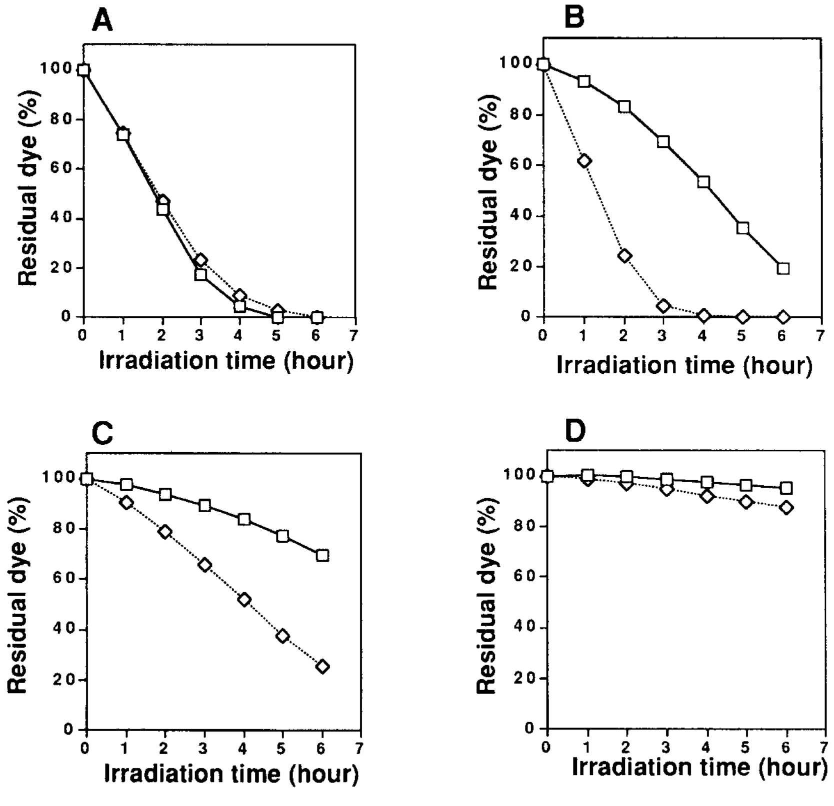

Fig. 7. Effect of polyester on decomposition of CI Disperse Red 60 in ethyl acetate: (A) 288 nm, (B) 316 nm, (C) 344 nm, (D) 372 nm. (□) Without polyester, (◇) with polyester.

If photoirradiation is carried out by light encompassing the entire wavelength range from the ultraviolet to the visible, (i.e. as in more conventional methods for the photoirradiation of dyed fibers), the findings obtained in this investigation might not be apparent. These factors would thus play an important role in the clarification of the photofading of dyed fibers, and contribute greatly to the design and development of dyes with high light fastness, and of ultraviolet absorbers for colored materials.

CONCLUSION

It was shown that CI Disperse Red 60, an anthraquinone type disperse dye, on polyester fiber was affected significantly by light at 316 nm, at which wavelength CI Disperse Red 73, an azo type disperse dye, was faded maximally as previously reported.[1] The photodegradation is independent of the structure of the dyes. CI Disperse Red 60 on diacetate and triacetate fibers underwent breakdown at 230 and 259 nm, respectively. The fibers themselves were also significantly influenced at the corresponding wavelengths, i.e. polyester at 316 nm, diacatete at 230 nm, and triacetate at 259 nm. The largest effect on the photodegradation is a specific fiber–wavelength combination. The photodegradation of the dye in ethyle acetate containing dissolved polyester also took place maximally at ca. 316 nm. These findings suggest that the photodegradation of dyes on a fiber is accelerated by the absorbed energy characteristic of the fiber and/or degradation products of the fiber generated at the characteristic wavelength.

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