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An Investigation of the Dyeability of Acrylic Fiber Via Microwave Irradiation

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ABSTRACT

Microwave dyeing was carried out under a variety of conditions in terms of the power and time of a microwave to investigate the effects of microwaving on the dyeability of acrylic fibers. It was found that the dyeability of acrylic fibers were significantly improved under microwave irradiation caused by the increased adsorption of the dye into fibers due to the local over heating and an amplified reaction probability between the dye and fiber. The physical properties of the acrylic fibers were elucidated using scanning electron microscopy (SEM), tensile strength measurements, and differential scanning calorimetry (DSC). The optimum time for the best dye uptake for given microwave powers was also reported. Prog. Color Colorants Coat. 1(2008) 57-63. © Institute for Colorants, Paint and Coatings.

1. Introduction

Presently, wool has been replaced, in many respects, by acrylic fiber, which is one of the most popular synthetic fibers [1, 2]. Acrylic fiber has extensive applications in apparel as well as in related industrial sectors owing to outstanding physical and chemical properties such as; high strength and good abrasion and insect resistance. However, strong hydrophobicity, low dye affinity and the propensity toward having a high static charge due to the lack of segmental mobility (resulting from intensive molecular orientation of the highly polar nitrile groups) has hampered this fiber from being efficiently used in the textile industries [3-5]

Furthermore, microwave-based dyeing methods have been studied as an alternative to conventional methods, with beneficial effects on processing time as well as mechanical and thermal properties [6-8]. Applications of this technology have been limited due to the difficulty in achieving even and controlled heating, especially for relatively large samples. In contrast to convection ovens, microwave heating is volumetric and not restricted to the surface [9]. The aim of the research reported here was to scrutinize the effect of microwave irradiation on the dyeability of acrylic fiber under various conditions in terms of power and duration of the microwave irradiation. The influence of microwave irradiation on the surface morphology, tensile strength, and thermal gravities (Tg) of fibers are also reported.

2. Experimental

2.1 Materials, equipments and instruments

LG™, MC-2003 microwave oven, was used for dyeing the acrylic fibers. The L*, a*, b* values of the dyed acrylic fibers was obtained using a Gretag Macbeth Color

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Eye 7000A Reflectance spectrophotometer. Scanning electron microscopic (SEM) analysis of the surface morphology of the acrylic fibers was performed using a LEO 1455 VP. UV/Vis spectra were recorded by UV/Vis spectrophotometer, CECIL CE 9200. Tensile strength of the acrylic fibers were obtained using a Shirley-SDLAtlas H5KT, England. Differential scanning calorimetry (DSC) analyses were carried out using a PerkinElmer, Pyris 6 DSC. Conventional dyeing method was done using High Temperature Laboratory Machine from Nasaj Sanat Company. Light fastness of dyed fiber samples was measured using Xnotest Beta LM. Basic Yellow 28 was synthesized as reported formerly [10] and was used for dyeing of acrylic fibers without any additive.

2.2. Methods

Conventional and microwave dyeing of acrylic fibers

As a conventional dyeing procedure, the dyeing bath was warmed from 40 $^{\circ}$C to 75 $^{\circ}$C at a rate of 3 °C/min, then heated to 105 $^{\circ}$C at a rate of 1 $^{\circ}$C/min and maintained for 60 minutes. Subsequently, it was cooled to 65 $^{\circ}$C at a rate of 2.9 $^{\circ}$C/ min .

Acrylic fibers were dyed using a microwave oven at various power settings (360, 540, 720 and 900W) for a range of durations.

For both methods, L:R (liquor to goods ratio, or the volume of liquor employed per weight of fabric) was 40:1.

Washing Fastness measurement

Washing Fastness for dyed fibers was measured by the Gray Scale and ISO 105-CO4 Standard method.

Tensile strength measurement

The fibers were cut into 50 pieces of 30 cm and subjected to measurement of the tensile strength.

Thermal gravities measurement

Relevant results of the DSC analysis of parent and dyed fibers by conventional and microwave methods were obtained using a rate of 10 $^{\circ}$C/min thermal on 5 mg of fibers.

Color Strength

Relative color strengths (K/S) were determined using the Kubelka-Mank equation (Eq. (1)):

$$K/S = (1 - R)^2/2R \qquad (1)$$

Where K, S and R are the absorption coefficient, scatter coefficient and reflectance of the dyed sample, respectively [11].

3. Results and discussion

Effects of microwave irradiation on the dyeability of acrylic fibers

Since a cationic dye is generally designed for dyeing acrylic fibers, that is widely used in manufacturing of blankets, carpets, knitting goods and also it has been proven that microwave irradiation is more effective on polar molecules [12-14], a cationic dye, Colour Index Basic Yellow 28, was used in this study and color depths after microwave dying were compared with conventional methods.

The results have revealed that acrylic fibers with improved color depth can be achieved in an extremely short time period using the microwave.

Both the power and duration of irradiation have shown significant influences on the dyeability of the fibers. Accordingly, the high power level and the short dyeing time will increase the dyeability of fibers compared to conventional methods. The optimum duration for each microwave power was: 10 mins at 900 W; 14 mins at 720 W; and 17 mins at 540 W. Satisfactory dye uptake and uniform dyeing were not achieved with any of the scheduled time lengths at a power of 360 W.

Although 5 minutes using 720 W microwave irradiation was enough to obtain the same dyeability as conventional methods, 14 minutes was assigned as the reference. At low concentrations of dye, adsorption using the microwave-based method is higher and much faster than that of conventional method, but K/S is the same after the saturation point (less than 1 % owf) as the saturation point is about 0.6 % owf (Figure 1).

The dyeability of the fibers using a microwave power of 720 W appears to plateau after 14 minutes, with similar results obtained using the conventional method only after 110 minutes. The influences of microwave power and length of irradiation time on color characterization of the dyed fibers are shown in Figures 2 to 4.

Table 1 shows the results of dyeing color depth of the acrylic fibers, under various conditions.

As shown in Figure 2, color depth is related to the power and length of irradiation. Superior color depth of the dyed fibers is obtained at high microwave powers in a much shorter time (about five minutes), but is reduced afterward. An inverse relationship has been found between the power of irradiation and the occurrence of such reduction (Figures 2 and 3). At low microwave power, dying requires additional time (up to 18 minutes).

As it is shown in Figures 3, the same patterns have also been obtained for a* and b* factors. Hence, in comparison to conventional methods, advanced efficacy may be attained using a microwave-based dying procedure without any unfavorable effects on color shade.

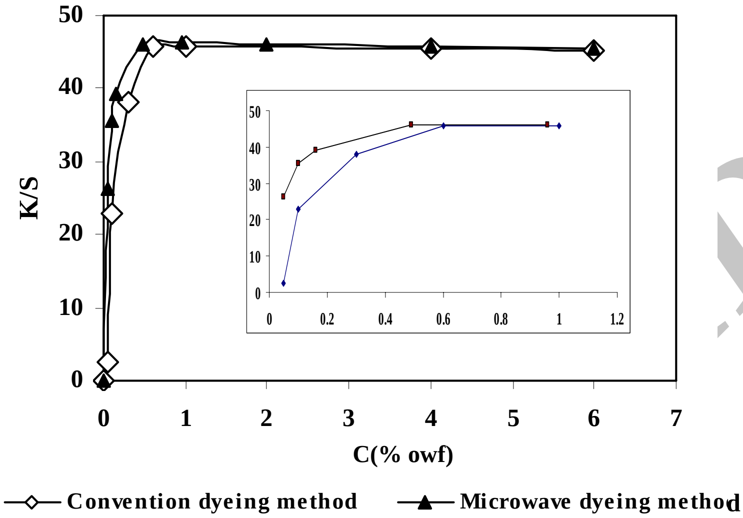


Figure 1: Relative color strengths (K/S) of fibers dyed using the microwave (at 720W /14 min) compared to conventional methods (110 min).

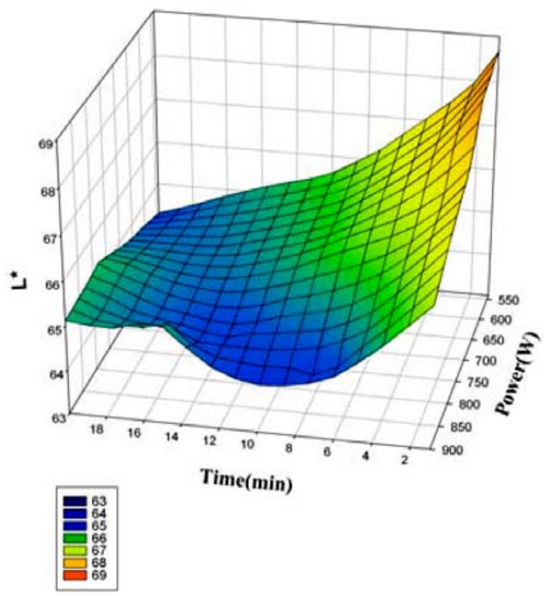


Figure 2: Influence of the power of the microwave and the time of dyeing on the color depth of the dyed fibers with 0.3 % dye.

Table 1 The dyeing color depth (L*) of acrylic fibers with microwave under various conditions in terms of power (P) , lengths of irradiation time (T) and also acrylic fibers were dyed with 0.3 % dye in dyeing bath.

No.	P	t	L*	No.	P	T	L*	No.	P	t	L*
1	900	1	66.809	12	900	12	64.51	23	540	5	66.435
2	900	2	65.368	13	720	3	66.582	24	540	7	65.752
3	900	3	65.06	14	720	5	65.87	25	540	10	65.392
4	900	4	64.96	15	720	7	65.71	26	540	13	65.448
5	900	5	64.77	16	720	10	65.48	27	540	15	65.2
6	900	6	64.239	17	720	12	64.791	28	540	16	64.999
7	900	7	63.97	18	720	14	63.654	29	540	17	64.245
8	900	8	63.91	19	720	15	65.103	30	540	19	64.251
9	900	9	63.454	20	720	17	64.946	31	540	20	64.45
10	900	10	63.459	21	720	20	64.979	32	Conventional method	110	64.137
11	900	11	64.36	22	540	3	68.547				

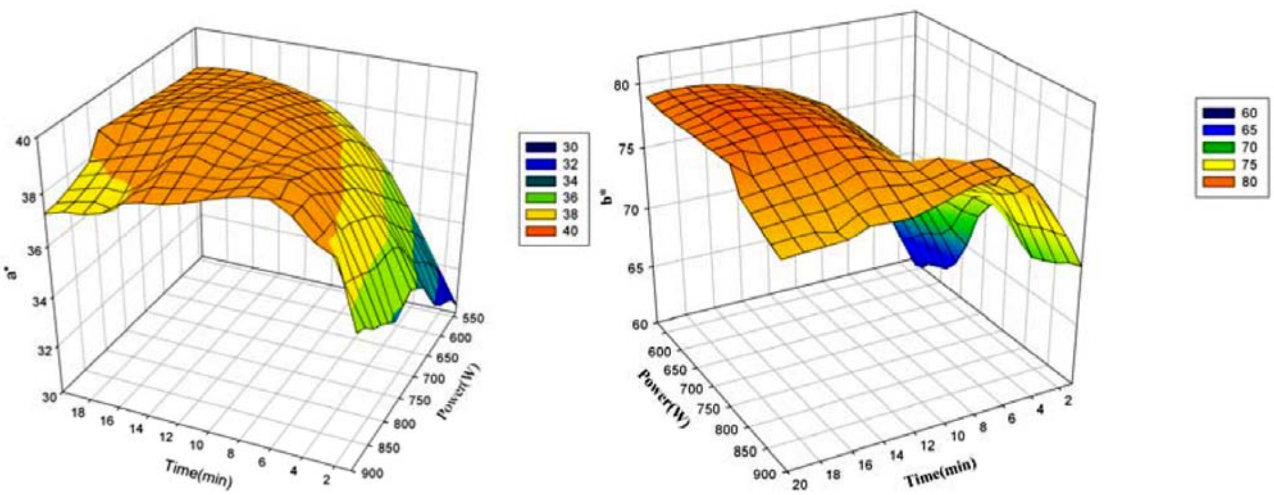


Figure 3: Influence of the power of the microwave and the time of dyeing on the a* and the b* of the dyed fibers with 0.3 % dye.

Effects of microwave irradiation on the surface morphology of acrylic fibers

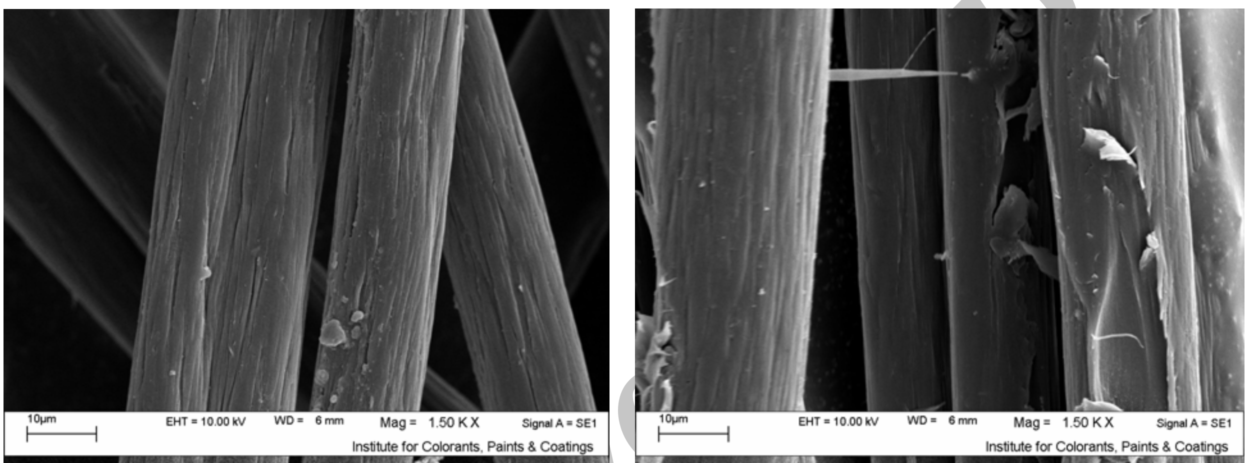
Effects of microwave irradiation on the surface morphology of acrylic fibers were examined by scanning electron microscopy. Figure 4 shows the SEM micrographs of conventional and microwave-based dyed acrylic fibers. Obviously, the surfaces of microwave-irradiated acrylic fibers were rougher than conventionally-dyed fibers. Thus, it can be concluded that the increased roughness of the surface under microwave irradiation improves adsorption and diffusion of the dye molecules into the acrylic fibers [6].

Effects of microwave irradiation on the tensile strength of acrylic fibers

Relevant results of the tensile strength analysis of fibers dyed by both conventional and microwave methods are given in Table 2. It is clear from Table 2 that the tensile strength decreases slightly after irradiation. The reason for such a decrease in tensile strength is considered to be due to ruptures occurring on the surface of dyed fibers under microwave irradiation. However, such a reduction in the tensile strength is not considered to be a significant cause for concern [15].

Effects of microwave irradiation on the thermal gravities of acrylic fibers

Relevant results of the DSC analysis of untreated and dyed fibers by conventional and microwave methods are given in Figure 5. It is clear from Figure 5 that the difference in glass transition temperature (Tg) between the parent and conventional or microwave-based dyed fibers are not considered to be a significant cause for concern [15].

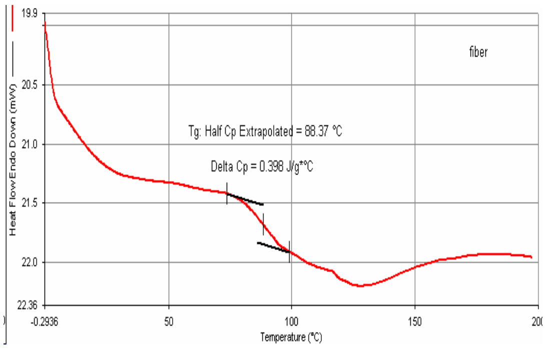


(a) (b)

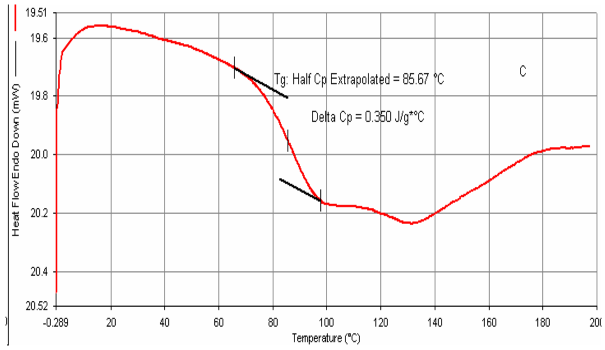
Figure 4: SEM micrographs showing the surface structure of (a) acrylic fibers dyed by conventional method, b) acrylic fibers dyed under microwave irradiation.

Table 2: Tensile strength of dyed fibers under conventional conditions and the microwave irradiations.

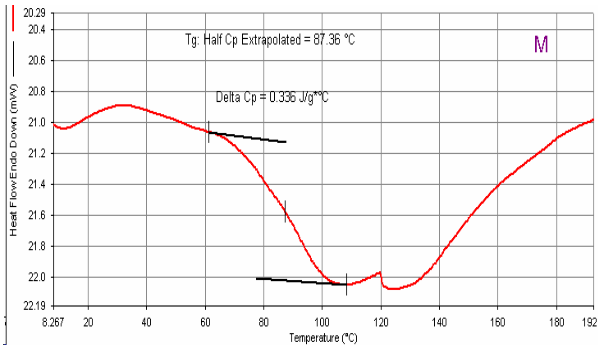
	Load at break (N)	Elongation at break	Strength (gr/tex)
dyed fibers under conventional conditions	25.37 (CV%=8.24)	14.60 (CV%=25/25)	7.93 (CV%=8.24)
dyed fibers under microwave irradiations	26.90 (CV%=1.3)	18.28 (CV%=23.78)	8.26 (CV%=1.3)



(a)



(b)



(c)

Figure 5: DSC analysis showing the Tg of a) parent acrylic fibers, b) acrylic fibers dyed by conventional method c) acrylic fibers dyed under microwave irradiation

4. Conclusions

The results have show that, at low concentrations of dye, adsorption using the microwave-based procedure is higher and much faster than conventional methods, but K/S is the same around the saturation point**.** The surfaces of microwave-irradiated acrylic fibers are rougher than conventionally dyed fibers, allowing the dye molecules to permeate and adsorb into the acrylic fibers. As a result, a reaction between the dye molecules and the acrylic fibers would be more probable. Differences in tensile strength and thermal gravity parameters for fibers dyed by conventional and microwave methods are not considered to be a significant cause for concern. Increased dyeability is related to the local over heating due to microwave irradiation [16] and the increased roughness of the fiber surface. A power of 720 W and microwave irradiation time of 14 minutes have been found to be an optimum dying condition for acrylic fibers, although 5 minutes using 720 W microwave irradiation is enough to obtain the same dyeability as conventional methods**.**

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