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Full Length Research Paper

Effects of corona discharge treatment on some properties of wool fabrics

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Worsted corona discharge was under operation, while the operation conditions were optimized. Processed woolen surface properties such as water absorption and staining properties were investigated. In addition, the bending length, wrinkle recovery and tensile strength retention (%) of treated samples were evaluated. Corona discharge after operation worsted water absorption property increased and the staining became high. The scanning electron microscope (SEM) showed that a number of scales on the surface epicuticle wool have dropped. The fourier transform infrared (FT-IR) analysis indicated that the rate of oxygen levels of wool increased and the rate of sulfur decreased after the operation.

Key words: Corona discharge, wool fabric, surface properties, SEM, absorption.

INTRODUCTION

Wool fiber, as a natural fiber, has a very complicated structure. Thus, there is specified scale surface wool felt that is likely to cause problems and create obstacles on the colorful surface materials in wool dyeing process. Chemical processes have been widely used for surface modification of fibers. According to the specified methods in the past and reducers, increases in reform were common wool fiber surface (Keab et al., 2008; Kan et al., 1998). However, it was found that during different processes, various chemicals produced from incomplete reactions ultimately cause pollutions (Kan et al., 1998). With the increase of ecological and economic constraints in textile industry, finding appropriate environmental strategies in wool operations processes appears to be essential. Accordingly, corona operation as a dry method is presented. Operation of the plasma as an effective technique for improving surface properties used for different types of textile reform has been determined (Zhu et al., 2002; Sun and Stylios., 2006; Wakida et al., 1993; De Puydt et al., 1989; Lehocky et al., 2006) as a kind of corona discharge plasma in processing operations on metal, and polymer materials has been considered (Wang et al., 2003; Zhu et al., 2006; Ristić et al., 2010; Wang et al., 2009; Brzeziński et al., 2010; Ma et al., 2009).

Due to an increase of ecological problems in wet finishing of wool fabrics, this present paper tries to investigate the effects of corona discharge treatment on the surface properties of wool fabrics. The surface chemical and physical composition and serviceability have been thoroughly perused on the basis of water absorption, SEM morphological investigations, relative color strength (K/S), FT-IR, bending properties, strength and elongation values, and dyeing rate measurement.

MATERIALS AND METHODS

The 100% wool twill fabrics (serge, 350 gm^{-2}) were selected for the samples. The linear densities of the end yarn and weft yarn were 20 × 2, and 18 tex, respectively. The sample size was 30 × 20 cm. All of the specimens were washed with deionized water, then dried and finally conditioned with atmospheric air (20°C, relative humidity 60%) before use. In order to dye the sample, C.I. Acid Red 138 (18073) was used. For spectroscopy absorbing spectrophotometer, Varian-Carry 100 Scan UV-visible and reflectance spectrophotometer Shimadzu 2550 UV/Vis spectrophotometer were used. FTIR, Bruker was also applied.

The fabric was treated by the corona discharge irradiation on the

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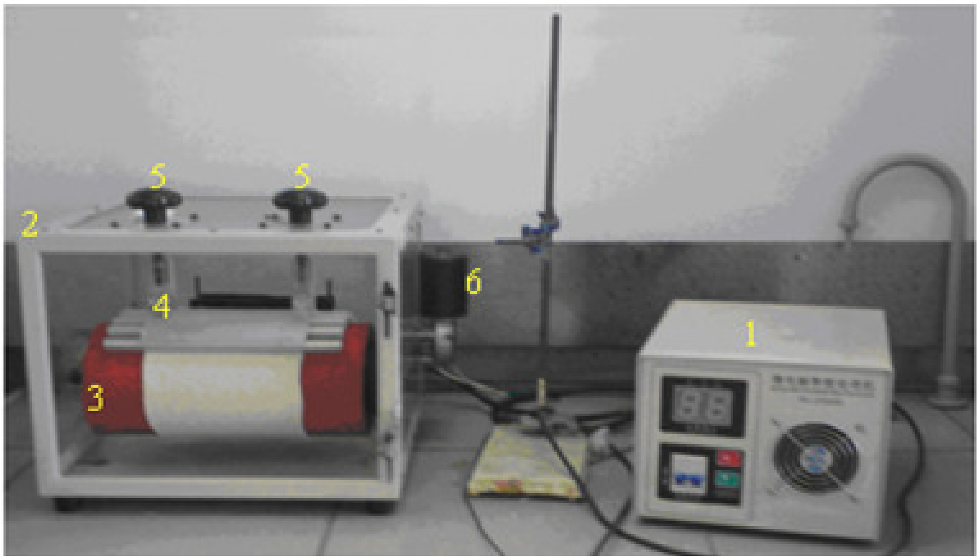

Figure 1. Equipments applied to perform corona treatment; 1: Power supply, 2: Container operations, 3: Roller and Sample, 4: Electrode spark production corona, 5: Electrode distance regulator screws up roller and 6: Electro motor.

Table 1. Conditions of corona operations on samples.

Sample number	Treating time (min)	Treating voltage (kV)
1	0	0
2	1	1
3	2	1
4	5	1
5	7	1
6	10	1
7	15	1
8	1	2
9	2	2
10	5	2
11	7	2
12	10	2
13	15	2

corona discharge machine of model DC-12-2W, which was produced by Sima Nassaj Research and Engineering Company.

Corona treatment

For corona treatment, a glow discharge generator was used with a DC source and luminescent evacuation was conducted in the presence of air. This is illustrated in Figure 1.

Corona discharge experiment was carried out (Table 1). The fabric was treated with corona at a constant output power of 4 kW and a voltage of 1 and 2 kV. In the reaction chamber, atmospheric air content was applied. Samples were placed on the electrode roll covered with silicon coating, rotating at the minimum speed set to 4 m/min. The distance between the electrodes was 2 mm. The treatment times on fabric were 1, 2, 5, 7, 10 and 15 min.

SEM morphological studies

The morphology of the treated and untreated wool fabric (control sample) was observed using a scanning electron microscopy (SEM LEO Electron Microscopy Ltd). For this purpose and since wool is an electrical insulator, the samples which were prepared in sputter coater were coated in vacuum with a layer of gold and a thickness of 2 µm.

FTIR spectroscopy

FTIR was used to investigate the probable changes in structural groups of corona treatment fabrics. For the purpose of IR spectroscopy, the samples with the dimension of 1 × 1 cm were Prepared and placed in the FTIR spectroscopy, and their infrared spectra were drawn.

By using this information and the peaks of graph for each sample, and also by according to standard adsorptions (showing the condition of group adsorption), the important structural groups were identified.

Dying rate

C.I. Acid Red 138 was used to dye the fabric. Dyeing ratio was 1:40, dye weight was 2% of the fabric, and the pH was 5.5. A certain weight of the fabric was immersed into the dyeing solution for 10 min at 40°C. The solution was then heated up at a rate of 1°C/min to 98°C and kept constant for 45 min, and then the dyeing rate was tested. Spectrophotometer was used to measure the absorbance of the dye solutions before and after exhaustion. The relative concentration of dyes was calculated based on a previously established absorbance–concentration relationship at λ_{max} (515 nm) of the dyes. The dye adsorption (%) of the fabric was estimated using the equation (1);

$$\text{Dye uptake \%} = (100 - C)\% \qquad (1)$$

Where, 100 and C% are the relative concentration of dye in the initial and the final bath, respectively.

Wool fabrics of the corona treated and untreated were dyed under the same conditions mentioned above. The K/S values of the dyed samples were determined using UV/vis spectrophotometer plus an integrating sphere attachment (ISR-240A, diameter 60 mm) and color-measuring software.

Measurements were taken with illuminant D65 and CIE 10° observer. During measurements, fabric samples were held flat using a spring-loaded sample clamp. Three measurements were repeated on each dyed fabric.

Relative color strength (K/S value) is a function of color depth and is represented by the equation of Kubelka–Munk (Equation 2)

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \qquad (2)$$

Where, R is the reflectance of the dyed fabric; K is the absorption coefficient and S is the scattering coefficient.

Moisture absorption

The moisture adsorption of untreated and treated corona wool fabric was measured using standard BS 4554. At least five specimens were tested.

This present test for fabrics containing fibers is hydrophilic. According to the time it takes (seconds), a drop of water going down the fabric is defined as the ability to be wet. According to this definition, some other fabrics which are hydrophobic require more than 20 s.

Strength and elongation test

In order to study the process of corona and achieving optimum conditions on the physical properties, strength and elongation were determined using a strength meter Enstron CRE (Constant rate of elongation) in accordance with the National Standard (ASTM D-1682-64). The samples size was 5 × 25 cm. All measurements were repeated for the thirty samples with the same treatment and then averaged.

Bending length

Bending stiffness properties of samples were evaluated using standard BS 3356. The length of the test specimen was 200 mm and the width 25 mm. All measurements were repeated for the thirty samples with the same treatment and averaged.

Wrinkle recovery

Wrinkle recovery angle (WRA) of the samples was evaluated using standard AATCC 66-1978. The samples size was 2 × 2 cm. All measurements were repeated for the fifteen samples with the same treatment and averaged.

In this experiment, samples were placed under the force of 500 g for 5 min, then the force immediately removed from the sample and wrinkle recovery angle (θ) was measured of the time domain 0, 5 and 10 min.

The ability to wrinkle recovery percent of the samples was estimated using the following equation:

$$W.R\% = \frac{\theta}{180°} \times 100 \qquad (3)$$

Where, θ is the crease recovery angle of the fabric.

RESULTS AND DISCUSSION

Surface morphology by SEM

SEM picture of wool fibers which were treated and untreated with corona are shown in Figure 2. It is obvious that the surface scale was more relaxed for the treated wool fibers as compared with the untreated ones. In addition, cracks and holes were visible on the wool fibers surface treated with corona. This is attributed to the etching effect caused by the bombardment of the air plasma species on the fibers surface. As a result, the specimen surface became rougher and coarser.

FT-IR study of corona treated wool fabric

In order to study the changes of chemical groups of samples under the corona treatment, FT-IR spectroscopy was performed. The FT-IR spectra of the untreated and corona treated wool fabrics are illustrated in Figure 3. Obviously, all of the spectra showed the typical signal patterns.

The changes of chemical groups during the corona treatment are depicted in Table 2. Results of FT-IR study indicate that there are not any structural changes in the molecular chain wool before and after the corona treatment, but the peak intensity of the groups containing oxygen and nitrogen in the treated samples increased. This shows that the group containing oxygen surface after processing is increased. The increase of the S-O and S=O groups was due to the S-S oxidation in the surface of wool after treatment. It means the decrease of

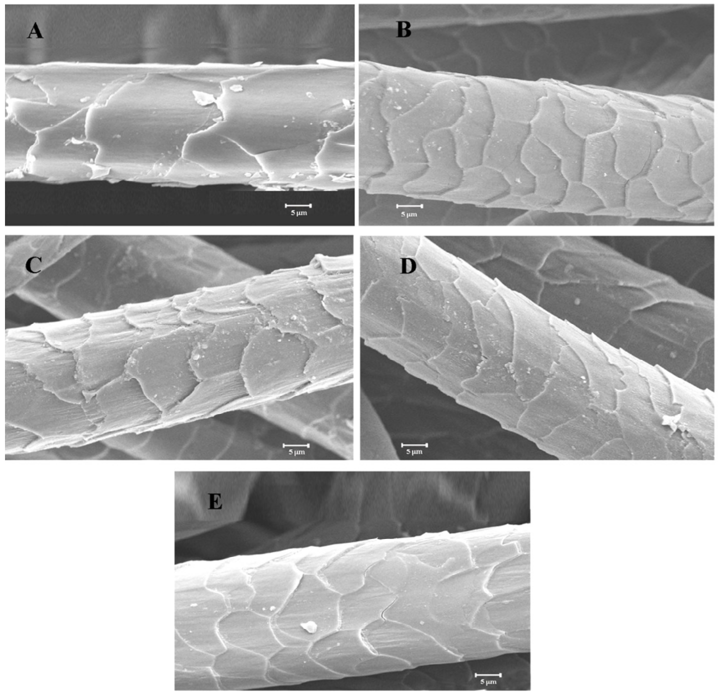

Figure 2. Surface morphology (SEM) of different wool fabrics, (A) untreated wool fiber, (B) corona discharge treated voltage 1kV - time 1 min, (C) corona discharge treated, voltage 2kV - time 1 min (D) corona discharge treated, voltage 1kV – time 7 min. and (E) corona discharge treated, voltage 2kV - time 7 min.

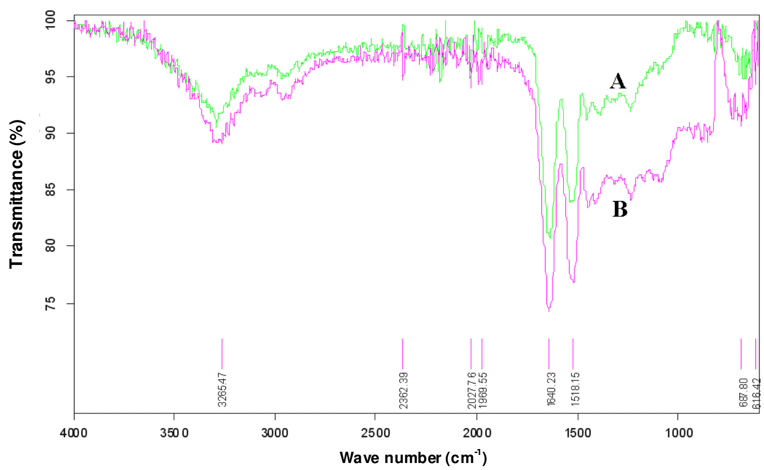

Figure 3. FT-IR spectra of untreated and corona treated wool fabric, (A) untreated wool fabric and (B) corona discharge treated (Treating voltage 2 kV and treating time 7 min).

-S-S- for the removal of cuticular from wool fiber.

Moisture absorption of corona treated wool fabric

The increased hydrophilicity of treated fabric is shown in Table 3 as a decrease in water absorbency time compared to the untreated fabric. Water absorbency time decreases from over 263 s to less than 10 s after corona treatment.

The sharply decreased water absorbency time can be explained by an increase in surface hydrophilicity and also the formation of micro cracks and the damage of Scales on the surface of fiber after corona treatment

Table 2. Chemical groups of samples

Type of vibration and group	Frequency (cm^{-1})
OH free	3265.47
OH with hydrogen bond	2362.39
N-H primary amine bending of N-H group	1640.23
NO_2	1518.15
C-N amine (C-O) carboxylic acid	1000-1350
S=O	1350
S–O	687

Table 3. Water absorbency time of untreated and corona treated wool fabric.

Sample number	Treating time (min)	Treating voltage (Kv)	Absorbency time (s)
1	0	0	263
2	1	1	14
3	2	1	14
4	5	1	12
5	7	1	11
6	10	1	8
7	15	1	8
8	1	2	7
9	2	2	7
10	5	2	6
11	7	2	4
12	10	2	3
13	15	2	2

(Figure 2).

With respect to the FT-IR Spectroscopy, It is expected that oxygen containing groups in the surface were produced after corona treatment (Figure 3). This plays an important role in increasing the chemical moisture adsorption.

Improving dyeing properties

In order to evaluate the effect of corona treated on wool dyeing and eventual process optimization, dye-bath absorbance was followed by on-line VIS spectrophotometry. Dyeing rate curves of untreated and corona treated samples are presented in Figure 4. Exhaustion curves define the time-dependant distribution of the dye between the dye-bath and wool fibers during the dyeing process, and indicate the dye adsorption on the fibers surfaces and the dye diffusion into the fibers depending on the time of dyeing, and corona treatment conditions.

As is evident from FT-IR analysis, corona treated wool fabric incorporated some oxygen groups such as –OH and –COOH in the wool surface and increased electro negativity. Simultaneously, some disulphide bonds in wool epicuticle were broken, making the wool more prone to wetting.

The surface morphology of untreated and corona treated wool fabrics analyzed by SEM was shown; the surface of untreated was smooth but that of the treated on the fiber surface for different condition showed more roughness, and also the formation of cracks on the epicuticle layers; therefore, the dye ability was accelerated.

The K/S values of the dyed untreated and corona treated fabric are shown in Figure 5, indicating that the relative color strength of the fabric increased as dyeing time prolonged. For the same type of fabric, the K/S value can be taken as the apparent dyeing rate that has a positive correlation with the dye amount in fabric surface, and therefore, the change of K/S value further confirmed the trend of dyeing rate. However, corona treatment was restricted to the substrate wool surface and did not

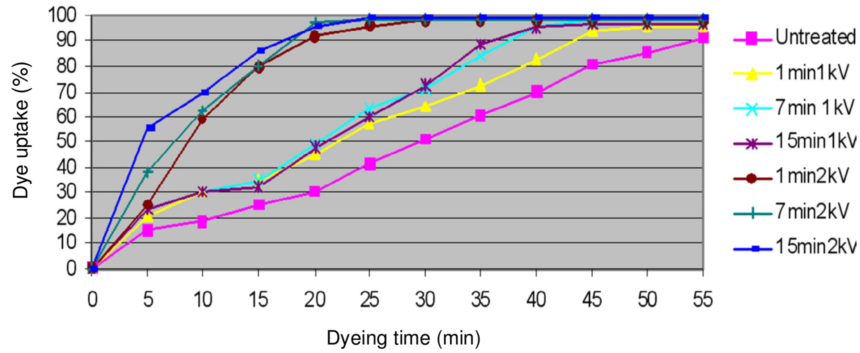

Figure 4. Dyeing rate curves of untreated and corona treated wool fabrics with C.I. Acid red 138 in concentration of 1%.

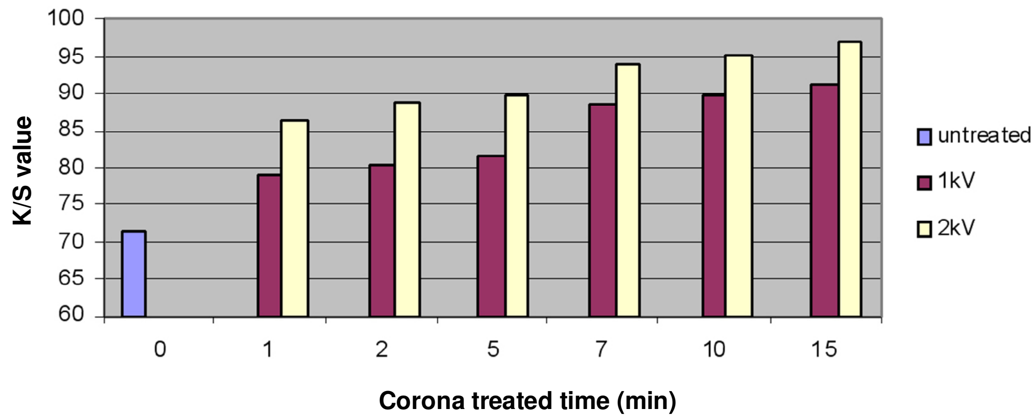

Figure 5. Relative color strength of dyed untreated and corona treated wool fabrics.

appear to affect bulk properties of wool fabric; thus, the final dye exhaustion and color depth of the treated fabric did not increase too much.

Strength and elongation of treated wool fabric

Table 4 shows the variation of strength and elongation of the untreated and corona treated wool fabric in the warp and weft direction with corona condition. The table illustrates a decreasing trend of the strength and elongation with treatment time and voltage.

Table 4 shows that the rate of strength in the process of corona treatment did not reduce greatly; however, there was a significant reduction in higher voltages and longer operation times. Of course, increase in voltage has a bigger share in this reduction. The reduction in operation strength seems to be the result of the atomic bond break in polymer chain fiber. This case is due to the effect of corona on the surface layer of the fiber.

The decrease in the breaking strength after the corona treatment seems to be in a good correlation with the SEM images of these fibers that seemed to be partially damaged (Figure 2). Apparently, corona treatments induced an increase in breaking strength in weft direction from 678.404 to 586.069 N and breaking strength in warp direction from 688.404 to 601.069 N.

Elongation changes are shown in Table 4, where increasing voltage and operation time elongation was reduced. The reason appears to be the formation of cross-connections between free radicals in corona environment in the side branch of the adjacent molecular chains.

It is to be mentioned that the less sensitivity of mechanical properties of textile to corona operations in lower voltages and in less time, is probably due to the effect of the textile tissue and also the tensions in the yarn on the operation results.

Effect of bending length and wrinkle recovery

These results of the bending length and the ability to change the wrinkle recovery of fabric in the warp and weft direction are presented in Tables 5 and 6.

It is clear from the results of Tables 5 and 6 that with voltage and corona effect duration increase, the bending in specimens increases as well.

Table 4. The variation of strength and elongation of the untreated and corona treated wool fabric in the warp and weft direction.

Sample number	Treating time (min)	Treating voltage (Kv)	Warp direction		Weft direction	
			Strength (N)	Elongation (mm)	Strength (N)	Elongation (mm)
1	0	0	688.404	27.24	678.404	25.24
2	1	1	669.422	26.66	658.422	23.66
3	2	1	653.325	26.24	641.325	21.24
4	5	1	633.201	25.24	622.201	20.24
5	7	1	622.431	24.34	610.431	19.34
6	10	1	620.422	23.34	601.431	18.34
7	15	1	601.069	21.00	586.069	16
8	1	2	633.201	24.10	633.201	22.10
9	2	2	622.122	23.10	622.122	21.13
10	5	2	610.041	22.80	610.041	19.80
11	7	2	578.833	19.20	578.833	18.20
12	10	2	570.306	16.30	570.306	16.30
13	15	2	460.781	14.03	460.781	13.03

Table 5. The variation of bending length of the untreated and corona treated wool fabric in the warp and weft direction.

Sample number	Treating time (min)	Treating voltage (kV)	Bending length (cm)	
			Waft	Warp
1	0	1	21	20
2	1	1	22	21
3	2	1	23.5	22.5
4	5	1	24	23
5	7	1	24.5	24
6	10	1	25.5	24.5
7	15	1	25	23
8	1	2	24	24
9	2	2	25	25
10	5	2	26	24
11	7	2	27	23
12	10	2	27.5	23
13	15	2	28	22

As mentioned before, all of the samples are to be tested in order to study the mechanical properties of fabrics corona treated to measure the angle of the wrinkles in the fabric in the warp and weft direction. These results are presented in Table 6.

Mechanical properties of fibers are considered a viscose elastic phenomenon. According to the obtained results, it can be that during the corona treatment, with increasing the voltage and operation time, the fabric wrinkle recovery decreases in the warp and weft direction.

Conclusion

Wool fabric can be modified by corona treatment, and this present experiment indicated that treating voltage was the most important factor in this regard. The optimum treating conditions were selected; treating voltage 1 kV, treating time 10 min or treating voltage 2 kV and treating time 5 min. After corona treatment, the surface properties of the wool fabric changed. SEM microscope images showed that the epicuticle scal during

Table 6. The variation of wrinkle recovery of the untreated and corona treated wool fabric in the warp and weft direction.

Sample number	Treating time (min)	Treating Voltage (Kv)	Wrinkle recovery %					
			Waft (min)			Warp (min)		
			0	5	10	0	5	10
1	0	0	68	78	78	64	76	79
2	1	1	67	76	77	64	75	78
3	2	1	67	76	77	63	75	78
4	5	1	66	75	76	63	75	78
5	7	1	65	74	76	62	74	77
6	10	1	64	74	75	62	74	77
7	15	1	64	72	75	62	73	77
8	1	2	63	73	76	62	74	77
9	2	2	62	73	75	61	72	76
10	5	2	62	71	74	61	71	76
11	7	2	60	70	72	60	71	76
12	10	2	59	70	70	58	71	75
13	1	2	55	69	68	56	70	74

operations became fewer and coarser so that after the operation, it is possible to inspect a small bore brush level on the fiber. FT-IR Spectroscopy analysis indicated that corona treatment changed the chemical composition of the wool fiber surface. Oxygen contents increased in the surface layer after treatment, without any effect on molecular structure of polymer chain. The hydrophilic property was also improved when the fabric was treated. After the treatment, dye-uptake ratio and dyeing speed were also improved; this can shorten the dyeing time and reduce the dyeing cost.

These results obtained from the observed changes in the physical properties of samples showed that voltage 2 kV and treating time 5 min did not have any effects on the strength properties of samples, but with increasing the time operation, the fiber was damaged and the strength diminished. Furthermore, these results obtained during the bending and wrinkle recovery tests indicate that the samples became slightly harder and their wrinkle recovery decreased which might be due to the corona effect on the link disulfide chain in the surface layers.

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