Stefan Brzeziński,
***Stefan Połowiński,**
Dorota Kowalczyk,
Grażyna Malinowska

Effect of Corona Discharge Treatment on the Surface Strength and Performance Properties of Synthetic Fibre Textiles

Textile Research Institute,
Research Division of Non-conventional Techniques and Textiles,
ul. Gdańska 118, 90-520 Łódź;

***Technical University of Łódź;**
Department of Physical Chemistry of Polymers,
ul. Żeromskiego116, 99-924 Łódź;

Abstract
Corona discharge, constituting one of the forms of atmospheric plasma, is a pro-ecological alternative to many conventional processes of the wet treatment of textiles that can also assist in improving these processes. However, one has to adapt the characteristics of corona discharge to the properties of the textiles to be treated and to use this plasma under controlled conditions, optimised to the results expected. An appropriate generator was designed and built equipped with a special multi-point electrode which makes it possible to obtain the extent of surface layer modification expected without any deterioration in the original strength properties of the textiles. The treatment of synthetic fabrics with corona discharge using the generator developed under optimised process conditions, brings about physical and chemical changes in the structure of the surface layer, resulting in a considerable modification of the surface strength and performance properties of textiles. The paper discusses changes in the properties of three selected types of woven fabrics from polyester, polyamide and polypropylene fibres treated with corona discharges, including wettability, the bonding strength of laminated fabrics, as well as the water-tightness and resistance of pigment printed fabrics for multiple washing. The results obtained confirm the usefulness of the preliminary treatment of textiles with corona discharge in improving their quality.

Key words: *corona discharge, synthetic fibres, textiles, strength, surface properties, performances properties.*

Introduction

The increasing threats to the environment, including the general harmfulness of conventional chemical treatments of fibres, performed mainly in aqueous media and requiring large quantities of water and thermal energy consumption as well as hardly biodegradable chemicals that pollute technological effluents, force one to intensify research oriented towards the development of more environmentally friendly technologies. One of the very promising trends includes processes based on the treatment of textiles with low-temperature plasmas [1, 4 - 7, 9]. As far astextile use is concerned, due to the low thermal resistance of textiles, only low-temperature plasmas can be taken into account; they include low-pressure plasmas generated and applied under low pressure conditions, mostly 0.1 – 1.0 hPa and plasmas generated and used under atmospheric pressure, commonly called atmospheric plasmas. Despite multiannual research as well as very interesting technological outcomes and considerable financial involvement, low-pressure plasma treatment has failed to gain industrial importance, with no likely turning point expected in the future. Atmospheric plasma, especially its modification through corona discharge, has been studied for more than 40 years, but the aim of those studies was mainly to modify plastic film surfaces in order to improve their printability as well as their joining and laminating capabilities [3, 4, 29]. The basic advantage of numerous atmospheric plasma varieties, including corona discharge, is primarily their generation and use under atmospheric conditions, which is of great technical and economic importance, as well as their high intensity of interacting with polymeric materials. This makes it possible to use short treatment durations and, consequently, to perform treatment by continuous methods with a considerably higher yield than in the case of batch processes, necessary for low-pressure plasma [1, 4, 14]. Corona discharges have found common use in the preliminary surface treatment of plastic films [3, 4], allowing the expected optimisation of their surface properties and, consequently, performance properties such as joinability and printability [3]. As the use of low-pressure plasma during recent years has failed to improve textile finishing, corona discharge has become the subject of research in this direction. However, the trials performed to adapt the technique of corona discharge used for plastic films directly to the purposes of textile treatment have failed to give the results expected, which was due to the principal differences in the structure of fibres and textiles made from them, e.g. woven fabrics and films of the same polymers – although a compact and homogeneous structure of film, it has a heterogeneous and porous textile structure , e.g. woven fabrics, with a coarse surface, made of fibres with circular or circular-like cross-sections. Hence, textiles have a lower sensitivity to the action of corona discharge, and consequently it is necessary to use considerably higher activation energies to obtain the modification degree expected than in the case of films [4, 7 - 9].

The aim of research carried out by numerous centres was first of all to reduce the main drawback of corona discharges: their high non-uniformity and to eliminate locally existing plasma channels with a high power: the so-called streamers, causing irreversible thermal damage to polymers, as well as to increase their modifying effectiveness. [1, 3, 8]. Finally, several different modifications of corona discharge have been developed, such as dielectric barrier discharges, diffusive coplanar barrier discharges, dielectric barrier discharges with plasma blow-in, and glow discharges occurring at radio frequencies [4, 17 - 40]. Such discharges can be generated both in air and selected gases (He, Ar, N_2), as well as in the atmosphere of an air-gas mixture. In order to generate such discharges, new types of discharge electrodes have been developed, e.g. electrodes in ceramic shields or segmental electrodes placed in a ceramic block. Suitable generators have also been developed for such discharges [3, 4, 8, 31, 35, 37 - 40]. Such generators are, however, expensive, which reduces their use in the treatment of textiles in industrial conditions.

Basic aim of the research

The basic aim of our studies was to examine the effects of corona discharges

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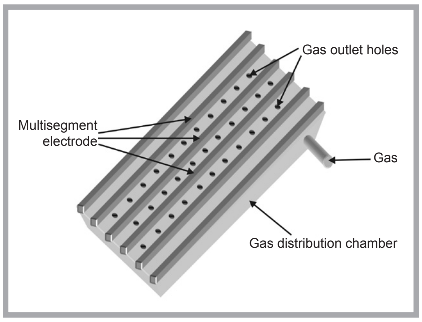

Figure 1. Constructional scheme of a multisegment electrode.

used under semi-industrial conditions on the changes in the physical and chemical properties of the top layer of synthetic fiber in terms of the possible use of these discharges for improving specific performance features of textiles. In these investigations we used an original corona discharge generator, developed and adapted by us for the treatment of textiles [8].

Experimental

Equipment used for the treatment of textiles with corona discharges

In the construction of our equipment, the above presented basic problem of the discrepancy between the necessity of obtaining a high energy corona discharge and simultaneously providing the highest possible uniformity and eliminating harmful streamers was solved by the development of an original system of dividing the corona discharge energy dose required per unit of the product surface activated in J/cm^2, whose quantified measure is E_j, into several smaller doses (n). E_{jn}, whose cumulative action on fibres/fabrics provides the level of plasma modification expected ($E_j = n \times E_{jn}$).

Such „constituent" doses of discharge energy are low enough to provide a high level of discharge uniformity and the elimination of streamers. To operate on this principle, an original system for a multi-segment electrode was designed and made; its constructional scheme is shown in ***Figure 1***. More details of the operation principle of the multi-segment electrode, the construction of electrodes and the corona discharge generator are presented in paper [8].

As confirmed by the tests performed , the system developed was effective, and the construction of multipoint electrodes was used in the equipment developed for the treatment of textiles with corona discharge, the scheme of which is shown in ***Figure 2*** [8].

Using this generator, we carried out systematic studies on the use of corona discharge for the modification of textile made from synthetic fibres, such as polyester (PET), polyamide (PA6) and polypropylene (PP) fibres. The studies performed resulted in interesting findings of a cognitive character, which also create real opportunities of practical utilisation.

Materials

Characteristics of the test materials, such as PET, PA6 and PP woven fabrics are presented in ***Table 1***.

Fabric treatment processes

Activation of woven fabric of synthetic fibre

The activation of fabric was carried out by means of a corona discharge generator equipped with multipoint electrodes (***Figure 1***), whose scheme is shown in ***Figure 2***. The technical parameters of this apparatus are described in [8]. The activation conditions were optimised so as to avoid appreciable damage to the fabric during modification as well as loss of its strength, and at the same time to provide expected physical and chemical changes in the surface properties of the fibres/fabrics [8, 10].

As a result of the systematically performed tests of the action of corona discharges with variable values of the following parameters: unit energy, E_j, generated with variable generator power, speeds of fabric movement through the discharge slot, the interelectrode slot size, amongst others, for selected fabrics made from three types of fibres: PET, PA6 and PP (***Table 1***), the optimised values of the unit energy [8] of activation of the fabrics tested were found with the use of the generator developed (***Figures 1*** & ***2***). It was found that under these conditions one can obtain considerable improvement in the fabric surface properties, as shown in ***Table 2***, with simultaneous elimination of the hazard of thermal damage to the fabrics, such as tensile strength deterioration, shown in ***Table 3***.

Fabric lamination

Lamination or the laminar joining of several, at least two, flat fabrics or fabrics with plastic films to obtain so-called composite fabrics with expected properties, dependant on the characteristics of their components and the binding polymeric layer, can be performed by various techniques such as laminating with appropriately applied solutions in organic solvents or aqueous dispersion of poly-

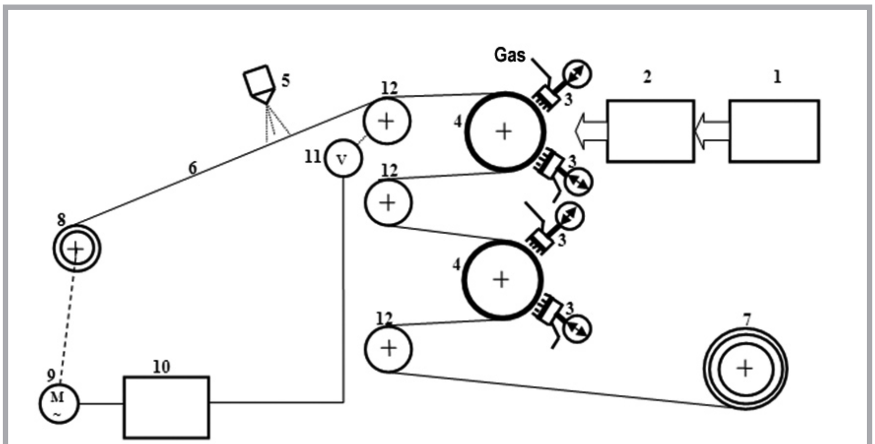

Figure 2. Block diagram of generator for the treatment of textiles with corona discharge: 1 - generator, 2 – high voltage transformer, 3 – five-segment discharge electrode, 4 – cylindrical electrode, 5 – nozzle of device for aerosol application, 6 – test material, 7 - rewinder, 8 - winder, 9 – drive motor of winder, 10 – frequency converter to control the rotational speed of winder motor, 11 – sensor of linear speed of test material, 12 – auxiliary roll [8].

Table 1. *Characteristic of the tested materials.*

Fibre (polymer) type	Warp		Weft		Surface weight g/m^2	Procedure of fabric preparation for discharge treatment
	Yarn features	Number of threads/10 cm	Yarn features	Number of threads/10 cm		
PET	84 dtex f 48 twistless spot tacked yarn	390	150 dtex f 216 twistless	320	89	Washing, heat-setting 20s. 190^{o}C
PA6	72 dtex f 17	380	160 dtex f 144	310	81	Washing, heat-setting 20s. 185^{o}C
PP	84 dtex f 33	460	84 dtex f 33	330	72	Washing

Table 2. Surface properties of PET, PA6 and PP woven fabrics treated with corona discharge under optimised conditions

Fabric type	Unit energy of activation, J/cm2	Selected surface properties of woven fabrics									
		Free surface energy, J/cm2		Wettability/capillarity degree, cm		Contact angle with water, deg		Content of acid groups, mol/g		O/C ratio (EDX method)	
		before activation	after activation	before activation	after activation	before activation	after activation	before activation	after activation	before activation	after activation
PET	75.6	38.45	48.16	5.45	10.65	63.35	51.03	0	$1.70*10^{-5}$	0.7588	0.7915
PA6	18.9	41.79	45.02	5.05	8.70	60.00	56.92	0	$2.81*10^{-5}$	0.3112	0.3440
PP	22.7	43.45	73.50	0.10	7.10	112.07	13.40	0	$1.94*10^{-5}$	0.0808	0.1748

meric binding agents, or techniques based on low-melting granulated polymers of the "Hot-Melt" type [5, 11 - 13, 17]. In our case, the first technique was used, and trials were carried out by means of a semitechnical line for padding, coating, laminating, drying and cross-linking, provided by Mathis (Switzerland) [5, 13]. A paste based on the aqueous dispersion of non-cross-linked, self-cross-linking acrylic-vinyl copolymer, Evo-Fin ATR from DyStar (Germany), in a quantity of about 50 g/m2 (about 15 g/m2 after drying), was applied on the surface of one of the fabrics joined (activated or unactivated under optimised conditions) by the method of thin-layer direct coating using a blade supported on a roll. Then, after a preliminary gelation of the coat with IR radiation, the second fabric (activated or unactivated) was overlaid, pressed with a roller, dried at 90 - 100 °C and cross-linked at a temperature of 160 °C for 60 s. Next, after conditioning for 24 h, the delaminating force of the laminated fabrics was determined. Considering the test objective (determination of the effect of preliminary activation on the lamination quality), woven fabrics of the same type were used in all the trials (with the same characteristics, activated or unactivated, respectively).

Watertight coating

To obtain watertight coats on the woven fabrics activated under optimised conditions or unactivated, coating pastes based on aqueous dispersion of non-cross-linked acrylic polymers [5, 12, 13] were applied to the fabrics by the method of direct thin-layer coating using a so-called air blade. All the three types of woven fabrics (activated and unactivated) were coated (***Table 1***) using the same laboratory line as in Section II (Fabric lamination). Washed and stabilised, or washed, stabilised and activated with corona discharge, the woven fabrics (***Tables 1*** and ***2***) were preliminarily padded with an aqueous bath containing 10 g/dm3 of an auxiliary agent based on fluoro-organic compounds - Oleophobol SL-AO1 from Huntsman (USA). This operation was used to avoid the coating paste penetration into the fabric structure, which would bring about too great a paste pick-up and considerable fabric stiffening.

Composition of the padding bath:
- 10 g/dm3 of Oleophobol SL-AO1
- 10 g/dm3 of isopropyl alcohol
- acetic acid to pH 4

Padding conditions:
- bath temperature 20 °C,
- bath pick up 70%.

After drying, the fabric was coated by the direct coating method with an air blade, using a paste with the following composition:
- 500 parts of Dicrylan AC from Huntsman – USA (non-cross-linked acrylic polymer in the form of 30% aqueous dispersion)
- 500 parts of Evo-Top CBW from DyStar – Germany (non-cross-linked urethane polymer)
- x parts of Lutexal HIT from BASF – Germany (polyacrylic thickener of pastes dispersed in water).

The woven fabric coated with the above paste was dried at 100 - 120 °C and cross-linked in hot air at a temperature of 140 °C for 3 min.

The coated fabrics, after acclimatisation, were padded with a bath of the following composition:
- 40 g/dm3 Oleophobol SL-AO1
- 10 g/dm3 isopropyl alcohol
- acetic acid to pH 4

Padding bath temperature:
- 20 °C;
- pick-up 50%.

The padded fabrics were then dried at 100 - 120 °C and polymerised at 140 °C for 3 min.

After the acclimatisation of the treated fabrics for 24 h, their water-tightness and changes were tested after standardised washing.

Pigment printing

Thanks to the colour qualities and generally good fastness of printed clothes, as well as the great simplicity and production reliability of pigment printing, its universality concerning practically all types of fibers and fabrics, the great progress in pigment and binding agent quality as well as relatively low production costs and favourable ecological aspects, this method of printing has gained primary importance over the past 15 years [2]. Pigment printed fabrics now constitute over 70% of all printed textiles made from cellulose fibres and from popular blends of cellulose and synthetic fibres. Synthetic fabrics have increasingly been printed by this method, particularly polypropylene (PP) fabrics, in the case of which pigment printing constitutes practically the only economical method of printing; however, this can also be said about polyester and polyamide fabrics [2].

In respect of the quality of printed fabrics, due to the technical characteristics of pigment printing, the critical parameters for the assessment of performance qualities include abrasion fastness, especially wet abrasion fastness tested under considerably severer conditions. This fastness depends first of all on the quality

Table 3. Dynamometric measurements of tensile strength.

Woven fabric	Unit energy of activation, J/cm2	Tensile strength, N	
		warp	weft
PET	0	539	1020
	75.6	578	1006
PA6	0	495	616
	18.9	490	623
PP	0	698	426
	22.7	693	432

of the polymeric binding agent used and, consequently, on the cross-linked print film and the force of its binding with the fibre/fabric surface, but also on the pigment particles dispersed in this film. On the other hand, it is the state of the fiber/fabric surface to be printed that is of paramount importance for the quality of print and its practical fastness. In this aspect, the use of corona discharge treatment resulting in effective physical and chemical modifications of the surface layer should lead to a noticeable improvement in both the conditions of the printing paste application and the degree of binding of the cross-linked printed film with the fibre/fabric surface, and consequently the print fastness obtained, especially wet fastness. This is of particular importance in the case of textiles made from synthetic fibres with a smooth and highly hydrophobic surface.

PET, PA6 and PP woven fabrics, presented in ***Table 1***, were used for testing, in which different procedures of their preparation for printing were used: a) only standard washing, rinsing, dehydration, drying and thermal stabilisation (only PET and PA6 fabrics) or b) the above procedures followed by an additional treatment with corona discharge under the optimised conditions given in ***Table 2***. The printing process was performed by the technique of hand screen printing with the use of flat patterns and typical printing pastes, which was the same for all the fabric types.

The flow chart for printing was the same for all the fabrics used and included:
Standard preliminary treatments (washing, drying, dehydration, heat-setting (only PET and PA6 fabrics)) → activation with corona discharge → printing → drying after printing → print fixing (thermal cross-linking).

The above series of operations was also used for printing unactivated fabrics (with no corona discharge treatment).

All the types of fabrics were printed with the same printing pastes of typical compositions:
- pigment pastes, Pigmatex from Sun Chemical A/S (Denmark) or Imperon from DyStar (Hoechst) (Germany), Fineprint (SOLCHEM srl, Italy) - 22 to 33 g/kg
- binding agent in the form of aqueous dispersion based on a self-cross-linking butadiene-acrylonitrile copolymer, Synthomer 5147 from Synthomer GmbH (Germany) - 130 to 150 g/kg
- synthetic thickener based on polyacrylic acid derivatives - 15 g/kg
- dispersing agent preventing the agglomeration of pigments in the printing paste - 5 g/kg
- anti-frothing agent - 5 g/kg.

The printing pastes used were of different colours: red (I), brown (II), violet (III) and dark blue (IV), containing the following additives :

I)	Pigmatex Orange OL	- 3 g/kg
	Fineprint Brown RB	- 1 g/kg
	Imperon Rot KGC	- 25 g/kg
II)	Imperon Rot KGC	- 25 g/kg
	Pigmatex Orange OL	- 5 g/kg
	Pigmatex Black NG	- 2.2 g/kg
III)	Pigmatex Rubin 2B	- 10 g/kg
	Pigmatex Violet 4B	- 7 g/kg
	Imperon Rot KGC	- 5 g/kg
IV)	Fineprint Navy Blue FRN	- 30 g/kg
	Pigmatex Violet 4B	- 5 g/kg
	Pigmatex Black NG	- 5 g/kg

Printed PET and PA6 fabrics were dried at a temperature ≤ 100 °C and then heated (cross-linked) in hot air at 150 °C for 5 min. In the case of PP fabrics, the cross-linking was carried out at a lower temperature adapted to the thermal properties of these fibres: 120 °C for 8 min.

Testing methods

Microscopic examination of the fibre surface
This examination was performed at a micro-scale with the use of the SEM method and at a nano-scale by means of the AFM technique, described in [8, 9].

Testing the chemical properties of the surface layer - X-ray micro-analysis (EDX)
For the purpose of the qualitative and quantitative chemical analysis of the surface composition, the X radiation was recorded by means of an EDX micro-analyser of the ISIS Link System from Oxford Instruments. The topography of the surfaces tested was observed by means of a Vega TS 5135 MM scanning electron microscope from Tesca. The resolution of the X-ray micro-analysis was about 0.5 μm [8, 9].

Measuring the contact angle and free surface energy
The contact angle of the fabrics tested was measured by the dynamic method using a Sigma 701 tensiometer (KSV Instruments Ltd., Finland). This method consists in recording the force acting on a sample of the fabric tested after having been immersed in and removed from the measuring liquid at the same rate. The free surface energy and its components were calculated as described in [7 - 9].

Wettability - capillarity testing
Capillarity tests were carried out in accordance with Standard PN-67/P- 04633 [41]. A description of this method and the determination procedure are given in [8].

Acid group content
The method used is described in our papers [8, 9].

Tensile strength testing
Tensile strength tests were performed according to Standard PN-EN ISO 13934-1:2002 [42], using a Zwick tester, model 1120 (Germany).

In addition to the tests mentioned above, the effect of corona discharge treatment on some selected performance properties of the fibre/fabrics was also assessed, assuming the following parameters:

Testing the delamination force of laminated fabrics.
Testing the adhesive properties of PET fabrics treated with corona discharge comprised the determination of the delamination force of laminates. In order to assess changes in the adhesive properties of fabrics treated with corona discharge, the forces of the delamination of two laminated fabrics were determined. Tests were carried out in accordance with Standard PN-P-04950:1988 [43], using a Zwick 1120 dynamometer, operating on the principle of constant elongation increment in time with recording the delamination force.

Testing the water-tightness of coated woven fabrics and their changes during standardised multiple washing
The testing was performed by the hydrostatic method according to Standard PN-EN 20811:1997 (Textile. Determination of water-tightness. Hydrostatic pressure method) [44], using a Penetrometer FX 3000 from TEXTEST A.G. (Switzerland).

Changes in water-tightness after multiple washing (5 washings) were assessed under standardised conditions according to Standard PN-EN ISO 6330:2002, procedure 5A (40 °C) [45], using an automatic washing machine - WASCATOR FoM 71 MP LAB from Electrolux (Sweden).

Testing the resistance of pigment printed fabrics to washing with wet brushing

In the case of pigment printed fabrics, the standardised test methods commonly used for testing the water, washing or perspiration fastness of fabrics printed with conventional dyes are of no use due to the form of pigment binding with the textile substrate and the pigment's insolubility in water. Only the methods of abrasion fastness, especially wet abrasion tests, can be used; however, the results obtained do not allow to assess the actual performance value of fabrics. Therefore manufacturers of pigments and binding agents develop their own test methods that allow more accurate assessment of the performance resistance of pigment printed fabrics. Such a wide-spread and most severe test method, additionally corresponding to conditions existing during the genuine use of fabrics, was developed by the company BASF - the so-called washing-with-brushing test. This method allows one to test changes in the colour of a sample using an assessment according to the grey scale or a method of objective colour measurement. The test procedure consists in washing a printed sample in an aqueous bath containing 5 g/dm^3 of soap and 3 g/dm^3 of sodium carbonate at boiling temperature for 30 min. at a liquor ratio of 1:50. After washing, the sample is first rinsed with hot and cold water, then squeezed out on a filter paper and finally brushed 10 times (in both directions) by means of a hand brush [2]. This method is recognised by us as the most suitable test procedure for assessing the effect of the corona discharge treatment of fabrics on their performance properties.

Results and discussion

Effect of corona discharge treatment on the surface properties of activated fabrics

As a result of systematically testing the physical and chemical charcteristics of woven fabrics treated with corona discharge generated under optimised process conditions by the generator developed (***Figure 2***), it was that it is possible to obtain a modification of the textiles under investigation (***Table 1***) and resultant changes in the surface layer structure the same as those observed in the case of polymeric films treated with corona discharge. Optimisation of the unit energy dose, *Ej*, provides the degree of modification expected and eliminates possible damage to the fibre-forming polymer, as confirmed by the fact that the tensile strength of the fabrics treated remains the same as that of unmodified fabrics (***Table 3***). The optimised doses of unit energy, *Ej*, and the surface properties of the treated fabrics obtained are given in ***Table 2***.

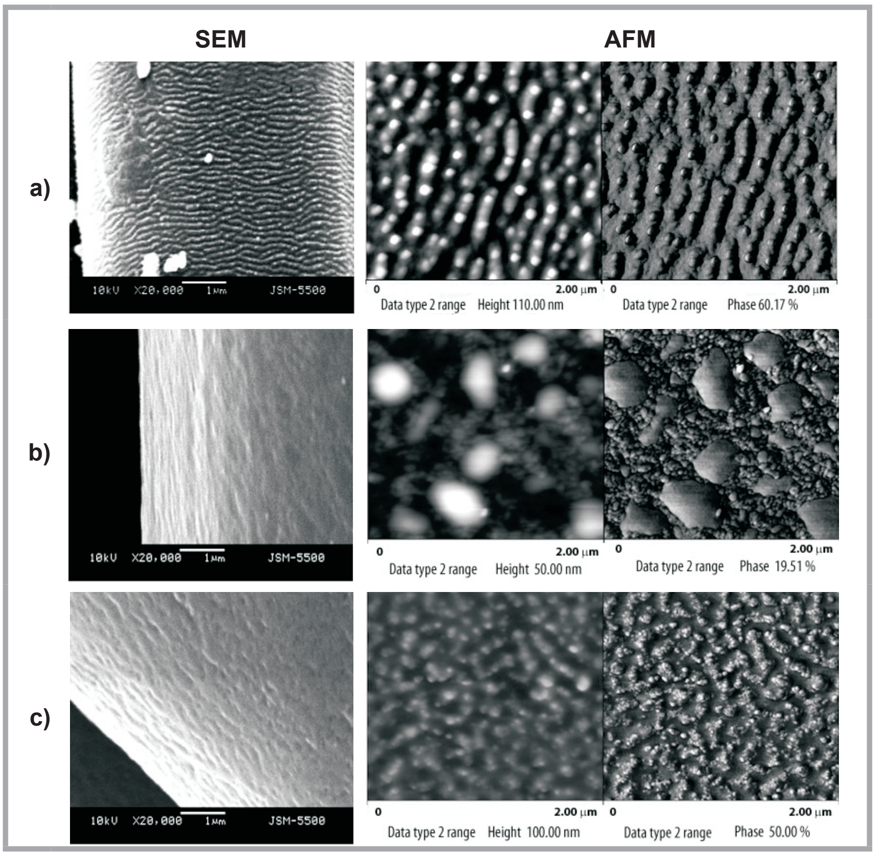

***Figure 3**. SEM (magnification x 20000) and AFM (left side - topography, right side phase) images of the activated fibres: a) PET (E_j=75,6 J/cm^2), b) PA6 (E_j=18,9 J/cm^2) and c) PP (E_j=22,68 J cm^2).*

The treatment of fabrics with corona discharge under optimised conditions resulted in changes in the micro- and nano-topography of the fiber's top layer as shown in ***Figure 3***.

As follows from the results listed in ***Table 2***, the changes in the surface properties of fibres/fabrics treated with corona discharge are very significant and similar to polymer-films - the characteristic globular nano-structure of surface layers [14-16].

These results confirm that the developed technique of applying corona discharges with the use of the generator developed is fully suitable for the modification of the woven fabrics under investigation.

The dynamometric measurements of the tensile strength of the fabrics performed before and after modification with corona discharge show no adverse changes, as shown in ***Table 3***.

Changes in the surface properties of fabrics – stability of the activation effects

Changes in the surface properties of activated woven fabrics occurring during their storage were assessed by measuring the fabric wettability by the method of capillarity measurement [41]. The results of these measurements for the 28-day period of fabric storage in a conditioned room are shown in ***Figure 4***.

As follows from the data presented, the improvement in the wettability of woven fabrics treated with corona discharge under optimised process conditions is a durable effect in time. After 22 - 28 days from activation, the wettability of PET fabrics was higher by 44% and that of PA6 fabrics by 57% in comparison with the wettability of unactivated fabrics. Slightly smaller changes were found in the case of PP fabrics.

Effect of corona discharge treatment on the wettability of fabric

The results presented in ***Table 2*** and illustrated in ***Figure 5*** show that the treat-

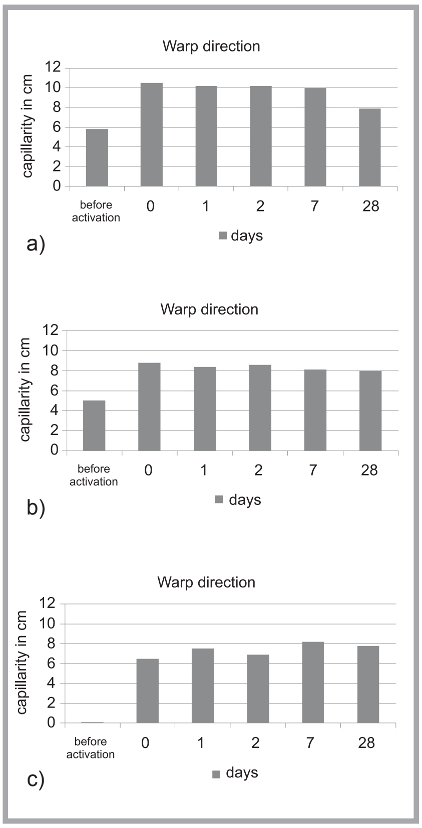

Figure 4. Changes in wettability/capillarity during fabric storage: a) PET, b) PA6 and c) PP.

ment of PET, PA6 and PP woven fabrics with corona discharge results in a considerable improvement in their wettability. This parameter is of great importance in a technical aspect as it not only influences the adhesive properties of the fabrics modified (adhesion energy) [7 – 10].

Fabric lamination - quality improvement of laminates

The test results confirm that the corona discharge treatment indeed increases the delamination force of laminated fabrics and has a direct positive effect on the quality of laminates. In the case of polyester woven fabrics in optimalised conditions, the increase in the delamination force is almost twice as high. In the case of PP fabric laminates, where it is particularly difficult to obtain a durable sizing effect, the treatment under discussion provided an increase in the delamination force of about 50%. This issue is presented in detail in paper [9].

Watertight coating - improvement in the water-tightness of coated fabrics

Table 4 lists the test results of changes in the water-tightness of coated fabrics due to their treatment with corona discharge and the resistance of the polymeric coat to multiple washing.

From the results above, it follows that the preliminary activation of PET and PP fabrics provides a considerable increase in the water-tightness of the coated fabric, which makes it resistant, to a large extent, to multiple washing.

Pigment printing - improvement in the fastness of pigment printed fabrics to washing and brushing

Table 5 lists the results of testing the fastness of pigment printed fabrics previously treated with corona discharge to boil washing with sequent wet brushing.

The presented test results of fastness to washing with wet brushing indicate that activation with corona discharges resulted in different effects depending on the type of polymer. The lowest increase in this fastness is observed in PET fabrics, while a higher increase can be seen in PA6 fibres. The best results were obtained for PP fibres. This very high increase in the fastness to washing with wet brushing obtained in corona-activated PP fibres seems to be due to the characteristics of polypropylene fibres. Based on the tests performed , it is clearly seen that preliminary activation with corona discharge can be recommended for all types of woven fabrics to be printed with pigment, as confirmed by the fastness results obtained.

Conclusions

1. The studies performed allowed us to develop optimised technological conditions for the modification of woven fabrics of continuous synthetic fibres with corona discharges, which make it possible to obtain a high degree of physical and chemical modification of the top layers of PET, PA6 and PP fibres, with the elimination of possible damage to the fibre-forming polymers, as confirmed by the unchanged strength properties of the fabrics modified.
2. Using appropriately selected conditions of corona discharge treatment in relation to the structure of the fabrics and fibre shape, one can obtain the extent of fabric modification/activation expected and thus appropriately form the technical and performance properties of textiles. The resultant changes in the structure of the surface layer are similar to those observed in the case of the action of corona discharge on the surface of films made from the same types of polymers.
3. Although there are essential differences between the conditions and effects of the surface modification of films and textiles from the same

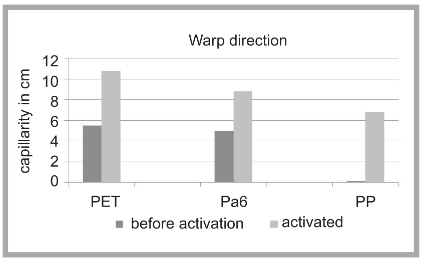

Figure 5. Improvement in fabric- wettability after corona discharge treatment.

Table 4. Results of the water-tightness of fabrics tested by the hydrostatic method.

Fabric type	Dry weight of polymeric coat, g/m²	Water-tightness measured by the hydrostatic method, cm	
		New fabric	Fabric after 5 washings
Unactivated PET fabric	31	98	53
Activated PET fabric	32	199	115
Unactivated PP fabric	28	104	48
Activated PP fabric	33	201	97

Table 5. Effect of corona discharge treatment of textiles on the fastness to abrasion of pigment printed fabrics.

Fabric type and treatment	Fastness to washing and wet brushing of pigment printed fabric according to BAF procedure – colour change in degrees of the grey scale			
	Colour of printed fabric			
	Dark blue	Violet	Red	Brown
Unactivated PET (blank sample)	4	4	3 - 4	4
Preliminarily activated PET	5	4 - 5	5	5
Unactivated PA6 (blank sample)	3	3	2 - 3	3
Preliminarily activated PA6	5	5	5	5
Unactivated PP (blank sample)	2 - 3	1 - 2	2	2
Preliminarily activated PP	5	5	5	5

polymers, in both cases the final effect produces the same characteristic globular nano-structure of the surface layers.

4. The beneficial changes obtained in the surface properties of PET, PA6, and PP woven fabrics due to their treatment with corona discharge under optimised conditions show good stability during fabric storage, which is of paramount importance for possible industrial uses of this innovative treatment technique.

5. The use of the preliminary corona discharge treatment of PET, PA6 and PP woven fabrics under optimised conditions makes it possible to improve considerably the technical and performance properties of modified fabrics, those modified and then laminated, as well as coated (to obtain water-tightness) or pigment printed fabrics. Taking into account the great importance of water-tight (and not only) textile-polymeric multi-layer coating materials as well as the considerably increased water-tightness parameter obtained due to preliminary corona discharge treatment, the numerous and miscellaneous uses of composite materials as well as the common use and importance of pigment printing, the aspects of the practical use of corona discharge treatment presented are of great importance and have high implementation opportunities.

6. The possibility of a considerable improvement in such an important parameter as wettability for the whole area of textile finishing, including a wide range of synthetic textiles, offered by corona discharge treatment, has a high potential of industrial implementation.

Editorial note

Unit activation energy, ***E_j* –** *the energy of corona discharge per unit area of the fabric activated.The value of E_j was calculated according to the formula:*

$$Ej = P_x B/LA \times 6 \cdot 10^{-3} \text{ in J/cm}^2$$

where: P_x – maximal rated power of the generator (2100 W); A – fabric passing rate in m/min.; B - discharge power in % ; L – length of discharge electrode in cm [3].

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References

1. Brzeziński S.: „Wybrane zagadnienia z chemicznej technologii obróbki włókna", Ed.: TUŁ 1999, Vol. 2 pp. 126-167.
2. Brzeziński S. : Drukarstwo Włókiennicze. Ed.: FRPK 2004. Vol. 2 pp. 87-110, 119.
3. Żenkiewicz M: Adhezja i modyfikowanie warstwy wierzchniej tworzyw wielkocząsteczkowych. Ed.: WNT, Warszawa 2000.
4. Shishoo R. „Plasma Technologies for Textiles", Woodhead Publ. Ltd., Cambridge 2007, p. 97-122.
5. Brzeziński S.: „Wybrane zagadnienia z chemicznej technologii obróbki włókna", Ed.: TUŁ 1999, vol. 3 pp. 146-168.
6. Brzeziński S.: „Perspektywy zastosowań nanotechnologii we włókiennictwie w Polsce." in Expertise of 4 Dep. WNT PAN, Warszawa 2006, pp. 10-34.
7. Brzeziński S., Kowalczyk D., Połowiński S.: FTEE, Vol. 17, No. 1(72) 2009 pp. 87-90.
8. Brzeziński S., Żenkiewicz M., Połowiński S., Kowalczyk D, Karbownik I., Lutomirski S., Malinowska G.: Polimery 54 (2009) No 6, pp. 421-429.
9. Brzeziński S., Połowiński S., Kowalczyk D, Karbownik I., Malinowska G.: FTEE Vol 17, No. 4(75) 2009 pp. 98-102
10. Brzeziński S., Żenkiewicz M., Połowiński S., Kowalczyk D, Karbownik I., Lutomirski S., Malinowska G.: Polimery, 54 (2009) No 7/8. in press.
11. Brzeziński S., Malinowska G., Nowak T.: FTEE, Vol. 13 No. 4(52) 2005 pp. 90-93.
12. Brzeziński S., Malinowska G., Nowak T., Schmidt H., Marcinkowska D., Kaleta A.: FTEE Vol.13 No. 6(54)2005 pp. 53-58.
13. Brzeziński S., Malinowska G., Robaczyńska K.: Spektrum Tekstylno-Włókiennicze Ed.: STW. vol 1 (2004) nr. 4 pp.15-18., vol. 2 (2004) nr. 5. pp. 16-17, vol. 3 (2004) nr. 6 pp.18--19., vol. 4 (2005) nr. 1. pp. 13-15.
14. Niemi H.E.-M., Denes F. S., Rowell R. M.: Langmuir, Vol. 15 (1999) pp. 2985-2992.
15. O`Hare L.-A., Leadley S., Parbhoo B.: Surf. Interface Anal. Vol. 33 (2002) pp. 335-342.
16. O`Hare L.-A., Smith J.A., Leadley S., Parbhoo B, Goodwin A.J., Watts nJ.F.: Surf. Interface Anal. Vol. 33 (2002) pp. 617-625.
17. Seeböck R., Esrom H., Charbonnier M., Romand M.; Plasma and polym. Vol. 5 (2000) pp. 103-118.
18. Klages C-P., Hőpfner K., Kläke N., Thyen R.; Plasma and polym. Vol. 5 (200) p. 79.
19. Lejeune M., Lacroix L., Brétagol F., Valsesia A., Colpo P., Rossi F.; Langmuir Vol. 22 (2006) p. 3057.
20. Strobel M., Jonem V., C. Lyons S., Ulsh M., Kusher M. J., Dorai R., Branch M. C.; Plasma and polym. Vol. 8 (2003) p. 61.
21. Laurens P., Petit S., Arefi-Khonsari F.; Plasma and polym. Vol. 8 (2003) p. 281.
22. Borcia G., Anderson C. A., Brown N. M. D.; Surf. Coat. Technol. Vol. 201 (2006) p. 3074.
23. Morent R., De Geyter N., Verschuren J., De Clerck K., Kiekens P., Leys C.; Surf. Coat. Technol. Vol. 202, nr. 14, 15 April 2008, pp. 3427-344.
24. Dumitrescu N., Borcia C.: Surf. Coat. Technol. Vol. 201 (2006) pp. 1117-1123.
25. Wang C .X., Liu Y., Xu H. L., Ren Y., Qiu Y. P.: Appl. Surf. Sc. Vol. 254 (2008) pp. 2499-2505.
26. Souto A.P., Carneiro N., Knott J., Rogister Y., Kaufmann R., Severich B., Höcker H.: „L`application des Traitements Corona dans l`Impression Textile". Proc. 17 IFATCC Congress, Ed.; IFATCC, Vienna, 1996, p.155.
27. Inagaki N.: „Plasma Surface Modification and Plasma Polymerization", Technomic, Lancaster 1996.
28. Hagemann D.: Proc. 1st Intern. Conf. „EuroNanoTex 2004", Paper № 13. Barcelona, 2004,
29. Żenkiewicz M., Lutomirski S.: Polimery, Vol. 46 (2001) p. 244.
30. Moravej M., Hicks R. F.: „Atmospheric Pressure Plasmas Principles and Operation", www.surfxtechnologies.com, (20.08.2008).
31. Šimor M., Ráhel J., Vojtek P., Černák M., Brablec A.: Appl. Phys. Lett. Vol. 81, (2002) p. 2716.
32. Parisi F., Pavan C., Dapra D.: Proc.of 21st Congress IFATCC, Paper No. F-36 Barcelona, 2008.
33. Rabe M.: Textil Veredlung, Vol. 41 (2006) No 9/10, p. 10.
34. Rabe M., Janssen E.: Proc. of 21st Congress IFATCC, Paper No. B-11, Barcelona, 2008.
35. von Arnim V., Dinkelmann A., Stegmaier T., Planck H., Rau A.: Textil Veredlung, Vol 43, No 1/2, (2008) p. 7.
36. Gassan J., Gutowski V. S.: Comp. Sci. and Technol. Vol. 60 (2000) p. 2857.
37. Černakova E., Kovačik D., Zahoranova A., Černak M., Mazŭr M.: Plasma Chem. Plasma Proces. Vol. 25 (2005) p. 427.
38. Zahoranová A., Kováčik D., Buček A., Ráheľ J., Černák M.: Proc. of VUTCH-CHEMITEX Conf., Paper 4, Žilina, 2007.
39. Fort S., Massafra M.R., Riccardi C.: Proc. of 21st IFATCC Congress, Paper No. B-29 Barcelona, 2008.
40. Carneiro N., Souto A., Foster F., Fernandes F., Dias P., Oliveira F.: Proc. of 21st IFATCC Congress, Paper No. F-30, Barcelona, 2008.
41. Standard PN-67/P-04633.
42. Standard PN-EN ISO 13934-1:2002.
43. Standard PN-88/P-04950.
44. Standard PN-EN 20811:1997.
45. Standard PN-EN ISO 6330.

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