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Effects of Atmospheric Pressure Plasma Treatments on Certain Properties of Cotton Fabrics

Abstract
In this study, air and argon atmospheric plasma were used for modifying some properties of bleached plain cotton fabrics. Certain physical properties such as pilling, thermal resistance, thermal conductivity, water vapour permeability, air permeability and surface morphology were evaluated as well. The outcomes revealed a remarkable increase in the pilling resistance of cotton fabrics after the atmospheric plasma treatments. The results also pointed out that the thermal resistance, water vapour permeability, and surface friction coefficient increased, although the thermal conductivity and air permeability decreased along with the atmospheric plasma treatments. The SEM images clearly showed that the atmospheric plasma modified the fibre surface outwardly.

Key words: *atmospheric plasma, cotton, pilling, physical properties.*

Introduction

Plasma treatment is a physicochemical method used for surface modification, as it affects the surface both physically and chemically without altering the material bulk properties [1 - 3]. Plasma is generated when gas is exposed to an electromagnetic field. The chemistry of the plasma takes place in non-equilibrium conditions [4]. The plasmas can be classified as being of the low pressure and atmospheric type. Both plasmas can be used for the surface cleaning, surface activation, surface etching, cross linking, chain scission, oxidation, grafting, and depositing of materials, and generally similar effects are obtained; however, atmospheric plasma has many advantages when compared with vacuum plasma. Vacuum systems are time, place and energy consuming processes, and material properties (thickness, size) are highly dependent on the size of the device. On the other hand, atmospheric plasma can be generated under atmospheric conditions and requires no vacuum systems with continuous and open perimeter fabric flow [5]. The efficiency of the plasma treatments depend on the treatment conditions [time, pressure, power, gas]. The species that participate in plasma reactions (excited atoms, free radicals and metastable particles, electrons and ions) can interact either physically or chemically with the substrate [6].

There are few previous works concerning the effects of plasma on the physical properties of natural based textile materials [3, 7 - 9], and most of them were carried out under low-pressure media. In this study, the effects of air and argon atmospheric plasma treatments on various physical properties of bleached cotton fabrics, such as, pilling tendency, friction coefficient, thermal comfort, water vapour permeability and surface properties were investigated.

Experimental procedure

Materials

Bleached cotton fabric was utilised for evaluating pilling, thermal resistance, thermal conductivity, water vapour and air permeability properties (***Table 1***.).

Table 1. *Fabric properties.*

Yarn count, Ne		Density	
Warp	Weft	Warp, ends cm^{-1}	Weft, ends cm^{-1}
21	23	26	24

Atmospheric Plasma Treatment of Fabrics

In this study, a dielectric barrier discharge (DBD) atmospheric plasma device was used [10]. The distance between the electrodes was 2 mm. Plain cotton fabric samples with an average thickness of 0.4 mm were passed between the electrodes continuously, and both sides of the fabric were exposed to the plasma treatment. In the treatments, air and argon were used as process gases under the power of 50, 100, 130 Watts; with different time durations of 20, 40 and 60 seconds.

Characterisation of modification

Due to the interactions between air and the activated surface, plasma treated fabrics were subjected to conditioning for 24 hours at 25 °C at a relative humidity of 65% .

Pilling tests were carried out on a Martindale wear & pilling tester according to Standard ISO 12945-2 . The outcomes were scaled as a number in the range of 5 (no change) to 1 (severe change).

Images of fabric hairiness were captured using a Motic light microscope.

The tensile strength was measured using a Lloyd LLOYDX-LR5K device according to Standard ISO 13934-1 standard.

To measure the kinetic friction coefficient of the fabric surface, a Frictorq instrument was used as described by Lima et al. [11].

The thermal conductivity and thermal resistance were measured with an Alambeta device constructed by Hes [12, 13].

A Permetest instrument was used to measure the relative water-vapour permeability [14].

The air permeability of the treated samples was measured according to method of Standard EN ISO 9237 using an FX 3300 air permeability tester (Switzerland).

For surface observation, changes in the fabric surface were evaluated using scanning electron microscopy (SEM). SEM observations were made with a Phillips XL-30S FEG scanning electron microscope.

The outcomes were analysed using analysis of variance (ANOVA) with an individual error rate of 0.05, and a ranking was obtained using the Newman-Keuls test.

Results and discussion

Pilling

Fabric-pilling is a serious problem for textile materials manufactured out of staple fibres. Pilling, which gives an undesired appearance to the garment, is the formation of small tangles of fibres or balls on the surface of a fabric as a result of any mechanical effect like abrasion or wearing. Pilling does not only affect the appearance and handle of the fabric, but also the service life of a product [15 - 17].

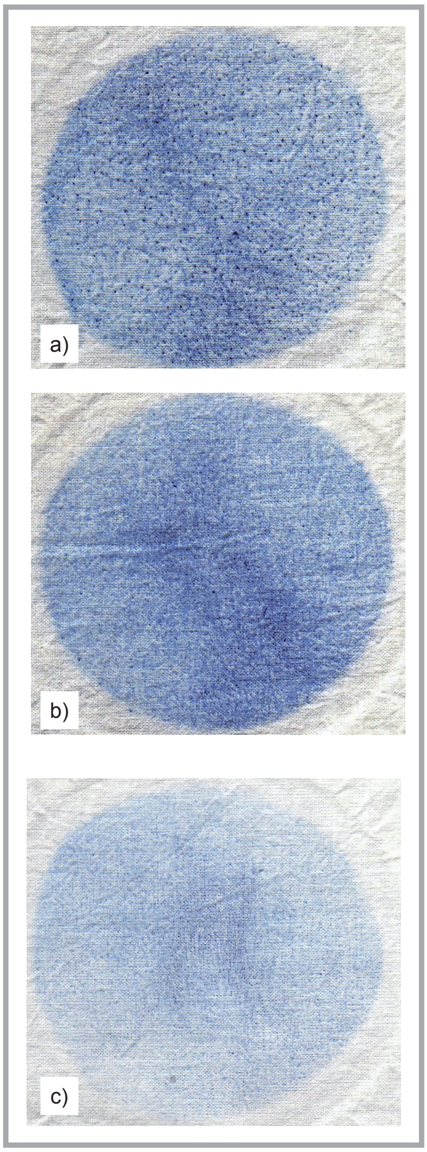
a)
b)
c)

Figure 1. *Pilling images of (a) untreated, (b)130 W 60 sec. air plasma treated, (c) 130 W 60 sec. argon plasma treated cotton fabrics.*

There are numerous factors which affect the pilling tendency of a fabric, such as fibre, yarn, or fabric properties, finishing processes and end-use parameters. In some cases, reducing the pilling tendency by controlling fibre, yarn, and fabric parameters becomes difficult because the attempt to control these factors may negatively affect the properties of the fabric . In this regard, various types of mechanical and chemical finishes can be useful in effectively reducing the number of fabric pills . However, the side-effects of these finishes should be taken into consideration [15].

Numerous research studies have been carried out concerning the prevention of the pilling tendency of cotton fabrics [14]. All these treatments aimed at weakening or eliminating the anchor fibres of the fabric in either production or finishing processes. Atmospheric plasma treatment is another physicochemical method that can be used for this purpose. As mentioned above, atmospheric plasma can be obtained by using different gases. From ***Figure 1*** and ***Table 2*** we can ascertain that both the air and argon plasmas improve the pilling resistance of cotton fabrics.

Singeing is generally used for cotton fabrics to achieve a smoother surface (better clarity in printing), improved visibility of the fabric structure, less pilling, and decreased contamination through the removal of fluff and lint. It usually involves passing/exposing one or both sides of the fabric over a gas flame: a kind of plasma which is generally obtained by using a mixture of certain hydrocarbons (in most cases propane (C_3H_8) and butane (C_4H_{10})). During this process, protruding fibres are burned off and the hairiness of the fabric is decreased. Although the atmospheric plasma used in this study was not as strong as singeing, a certain level of reduction in the hairiness of the fabric was achieved, as can be seen from ***Figure 2.*** The probable cause of the decrease in pilling might be the reduction in the hairiness of the fabric.

Also we assumed that the etching action of the atmospheric plasma treatment weakened the structure of the anchor fibres, therefore they became more fragile [18]. As a result of these alterations, the abrasion resistance decreased. In other words, atmospheric plasma increased the speed of the pill detachment to a level higher than the speed of pill formation without imposing any significant decrease in the tensile strength. The tensile strength was decreased from 501.9 to 500.1 N for the air plasma treated and to 500.0 N for argon plasma treated cotton fabrics under 130 W 60 sec. treatment conditions. The

Table 2. *Pilling outcomes.*

Treatment	Pilling	
	Mean	
	Air Plasma	Argon Plasma
Untreated	1.35	
50 W 20 sec.	1.35	1.375
50 W 40 sec.	1.85	2
50 W 60 sec.	1.925	2.5
100 W 20 sec.	2	2.275
100 W 40 sec.	3.65	4.65
100 W 60 sec.	4.375	4.7
130 W 20 sec.	4	4.55
130 W 40 sec.	4.65	4.65
130 W 60 sec.	4.7	4.7

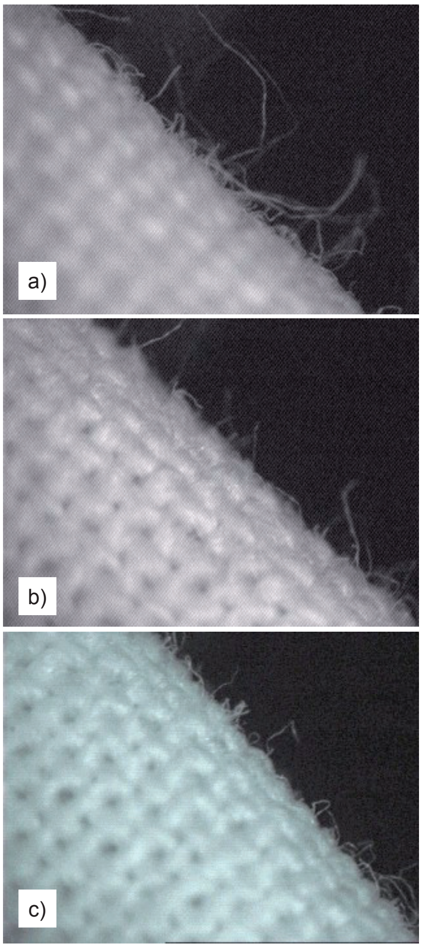
a)
b)
c)

Figure 2. *Light microscope images of hairness on cotton fabrics (a) untreated (b) 130 W 60 sec. air plasma treated (c) 130 W 60 sec. argon plasma treated cotton fabrics.*

outcomes obtained were quite consistent with the nature of the plasma interaction because it did not affect the bulk properties of the fabric negatively [2 - 4].

Thermal resistance and conductivity

According to the results in ***Tables 3*** and ***4,*** while the thermal resistance increased, the thermal conductivity decreased gradually with an increase in the applied power and exposure time. As was tested with ANOVA, the thermal resistance and thermal conductivity of the cotton fabric were affected by the plasma treatment. For thermal resistance the effect of the applied power, exposure time and gas type were found significant, whereas the gas type was not found to be significant in terms of thermal conductivity. As seen in ***Tables 3*** & ***4***, the plasma treated fabrics had better insulation properties compared to the untreated fabric. The thermal properties of the fabric greatly depended on the air trapped within it [19]. As stated above, the atmospheric plasma treatment had an etching effect on the fibre surface and increased the fabric surface roughness and space, which might increase the amount of air kept between the yarns and fibres [3, 8, 9]. The air which was kept inside the fabric could act as a good insulation medium and helped to prevent heat loss in the fabrics; this was likely to be the cause of increased thermal resistance and decreased thermal conductivity.

Relative water vapour permeability

Results relating to the relative water vapour permeability are given in ***Table 5***. The improvement in the water vapour permeability of the cotton fabrics was found to be significant. On the other hand, the difference between air and argon plasma was not judged significant. In the case of fibrous materials, the surface properties and pore structure of the material are of importance in terms of liquid transfer properties. These results probably stemmed from the groves formed and the cracks over the surface. These cracks might cause a decrease in the capillary pressure, which probably causes higher water vapour permeability [20, 21]. In other words, a feeling of better comfort can be provided by increased vapour permeability with the help of plasma treatment.

Air permeability

The outcomes related to the air permeability indicated that the atmospheric plasma treated fabrics had poorer air per-

Table 3. *Thermal resistance outcomes in* m^2 KW^{-1}*.*

	Thermal resistance × 10^4			
Untreated	mean = 128.4		standard error = 0.104	
Treatment	**Air plasma**		**Argon plasma**	
	Mean	**Standard error**	**Mean**	**Standard error**
50 W 20 sec.	135.2	0.110	136.6	0.047
50 W 40 sec.	137.6	0.130	139.6	0.130
50 W 60 sec.	138.3	0.071	145.0	0.141
100 W 20 sec.	137.4	0.141	140.4	0.122
100 W 40 sec.	141.6	0.202	144.8	0.202
100 W 60 sec.	142.8	0.202	146.0	0.184
130 W 20 sec.	141.6	0.158	144.4	0.122
130 W 40 sec.	142.4	0.122	145.6	0.095
130 W 60 sec.	147.2	0.164	154.0	0.167

Table 4. *Thermal conductivity outcomes (*Wm^{-1}K^{-1}*).*

	Thermal conductivity × 10^4			
Untreated	mean = 447.4		standard error = 0.071	
Treatment	**Air plasma**		**Argon plasma**	
	Mean	**Standard error**	**Mean**	**Standard error**
50 W 20 sec.	438.6	1.581	440.6	1.000
50 W 40 sec.	435.0	0.241	435.2	0.184
50 W 60 sec.	431.2	0.071	432.0	0.707
100 W 20 sec.	430.8	0.032	430.8	0.100
100 W 40 sec.	422.0	1.000	423.6	0.141
100 W 60 sec.	413.6	0.100	414.4	0.100
130 W 20 sec.	426.6	0.032	427.4	0.071
130 W 40 sec.	420.2	0.071	421.0	0.707
130 W 60 sec.	404.8	0.118	406.0	0.707

Table 5. *Relative water vapour permeability in %.*

	Relative water vapour permeability			
Untreated	mean = 50.55		standard error = 0.0063	
Treatment	**Air plasma**		**Argon plasma**	
	Mean	**Standard error**	**Mean**	**Standard error**
50 W 20 sec.	51.38	0.1044	51.69	0.0715
50 W 40 sec.	51.91	0.0322	52.77	0.0385
50 W 60 sec.	52.05	0.0311	55.55	0.0152
100 W 20 sec.	51.66	0.0291	52.22	0.0071
100 W 40 sec.	52.22	0.0031	53.10	0.0352
100 W 60 sec.	57.61	0.0212	57.89	0.0247
130 W 20 sec.	52.04	0.0374	52.63	0.0647
130 W 40 sec.	56.73	0.0565	58.33	0.0235
130 W 60 sec.	58.62	0.0207	58.75	0.0474

Table 6. *Air permeability (*l/m^2 s*).*

	Relative water vapour permeability			
Untreated	mean = 342		standard error = 0.748	
Treatment	**Air plasma**		**Argon plasma**	
	Mean	**Standard error**	**Mean**	**Standard error**
50 W 20 sec.	342	0.707	342	0.707
50 W 40 sec.	341	0.949	341	1.378
50 W 60 sec.	339	0.707	338	0.316
100 W 20 sec.	340	0.894	339	0.707
100 W 40 sec.	338	0.316	337	0.894
100 W 60 sec.	336	0.707	335	0.837
130 W 20 sec.	338	1.517	337	0.707
130 W 40 sec.	336	0.707	335	0.894
130 W 60 sec.	334	1.225	333	1.095

meability (***Table 6***). While this difference was found statistically significant; the difference between air and argon plasma was not found significant. Etched fibres act as a boundary to hinder the air flow through the fabric, which causes a reduction of the air permeability of the fabrics. Air kept within the plasma treated fabric could not escape easily [9].

Surface observations

The surfaces of the fabrics were morphologically observed by SEM. ***Figure 3*** shows the surface appearances of the treated and untreated cotton samples and enables to make a visual comparison.

It is clearly apparent in the pictures that the untreated cotton fibre has a smoother surface. The salient microcracks and groves, which occurred because of the etching effect of plasma treatment, can be seen clearly. The argon plasma treated cotton fibre has more groves than the air plasma treated one due to the higher etching tendency of the argon plasma [7, 9, 22]. These images present a consistent scheme of the surface friction coefficient properties. For the samples treated under 130 W, for 60 sec., the surface friction coefficient was increased from 0.2681 to 0.2739 for those air plasma treated and to 0.2743 for argon plasma treated cotton fabrics; the difference was found statistically significant.

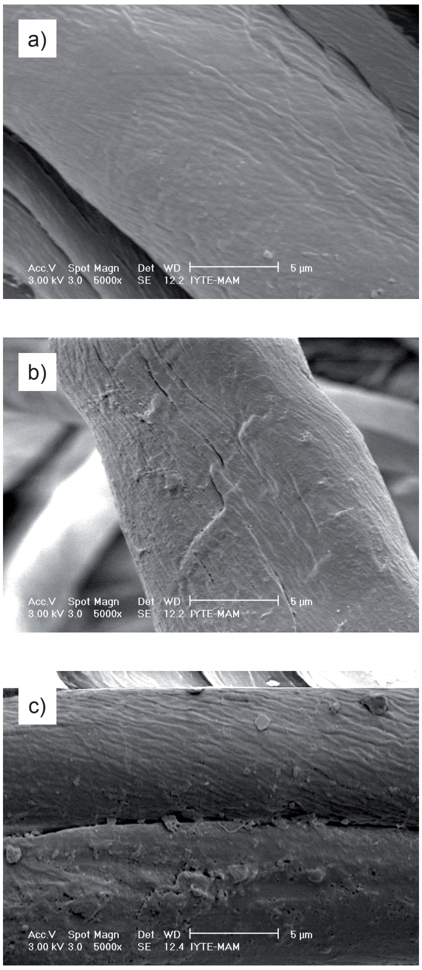

Figure 3. *SEM micrographs of (a) untreated (b) air plasma treated and (c) argon plasma treated cotton fabrics (130 W, 60 sec.).*

Conclusions

This research was an attempt to develop less energy demanding, clean and dry textile finishing processes. The primary aim of this study was to investigate the effects of atmospheric plasma treatments on various properties of plain bleached cotton fabric. The outcomes revealed that the pilling resistance of the aforementioned cotton fabric increased considerably without any chemical or water requirement and without a significant decrease in tensile strength. The SEM pictures clearly show that the atmospheric plasma was an effective method of etching the fibre surface.

Although in our previous studies [18] argon was found to be more effective than air plasma for raw cotton fabrics; the same effect was not obtained for bleached cotton fabric. This may probably be due to the removal of the hydrophobic layer of the cotton fibres during pretreatment. In this case, it is possible to state that the main parameters which had the strongest effects during the plasma treatment were the duration of the treatment and the applied power range. As no significant difference was found between the air and argon plasma treated samples in terms of thermal conductivity, air permeability and relative water vapour permeability, expenses can be minimised by using air as a process gas instead of argon, without compromising the effect.

As is known, the pilling tendency and comfort properties of cotton fabrics mainly depend on factors such as the raw material, yarn structure, yarn density, fabric construction, fabric thickness, fabric weight, finishing parameters and so on. In this area more research effort should be devoted to establishing the pilling mechanism and changes in the comfort properties of atmospheric plasma treated fabrics.

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