Surface modification of nonwoven fabrics using low pressure plasma with a mixture gas for filtration applications

O. Fenollar[1], R. Balart[1], D. García[1], R. López[2], M. A. Bonet[3]

[1] *Materials Technology Institute (ITM)*
Polytechnic University of Valencia
Plaza Ferrandiz y Carbonell s/n, 03801, Alcoy (Alicante) Spain
[2] *Textile Research Institute (AITEX)*
Plaza Emilio Sala s/n, 03801, Alcoy (Alicante) Spain
[3] *Department of Textile and Paper Engineering*
Polytechnic University of Valencia (Campus Alcoy)
Plaza Ferrandiz y Carbonell s/n, 03801, Alcoy (Alicante) Spain

INTRODUCTION

Nonwovens textile fabrics are a versatile engineering material, that are used in a great variety of applications ranging from baby diapers to industrial high performance textiles including liquid and gas filtration. On the hand, the nonwoven industry is one of the fastest growing industries in the world. It has been exhibiting an average growth of about 10% over the past twenty years and should continue this rate of growth in the next ten years [1-3].

Nonwoven filtration media has existed for hundreds of years in one form or another, including wool felt and cellulose However appearance of the synthetic polymer like polyester or polypropylene promoted the increasing of its use as coolant and water filtration. These applications need in many cases good adhesive properties and high wettability. Regarding to this polypropylene (PP) has a strong hydrophobicity [4-8].

In this study, hydrophobic nonwoven polypropylene was treated with methane-oxygen gas plasma activation and subsequent plasmapolymerization to modify its surface hydrophilicity [9-13]. The gas methane-oxygen ratio used was 80:20. The effect of the variation of the plasma treatment conditions has been studied in order to optimize the plasma treatment. The film wettability has been analyzed by the study of the variation of the contact angle and free surface energy calculation. The nonwoven surface topography was analyzed by scanning electron microscopy (SEM).

The plasma treatment containing an organic monomer (methane) deposites activated molecules on the surface material. On the other hand the activation/functionalization of the surface was obtained by several ways in function of the processing condition. By this way, the activation is obtained by inserting active species, surface abrasion or cross-linking processes. The final result of plasma treatment is an increase of surface energy of nonwovens and consequently an improvement of wettability properties; in addition an improvement of aging behavior is experimented.

EXPERIMENTAL

PP films were exposed to radio frequency (RF) low pressure CH_4-O_2 plasma. It was used a glow discharge RF generator (operating at 13.56 MHz with a maximum power

of 150 W) type CD 400 MC option PC (Europlasma, Oudenaarde, Belgium). The plasma chamber consists of four aluminium shelves for sample holder and a total volume of 64 l. The gas used for the plasma generation was a mixture of CH_4-O_2 with a 80:20 volume ratio. It was used a gas flow rate of 100 cm^3min^{-1} and the working pressure varied in the 31-32 Pa range. The treatment power varied in the 50-150 W range.

X-ray photoelectron spectroscopy (XPS) analysis was carried out with a VG-Microtech Multilab (Thermo Fisher Scientific Inc., Waltham, USA) electron spectrometer, by using the Mg Kα (1253.6 eV) radiation of twin anode in the constant analyzer energy mode with pass energy of 50 eV. Pressure of the analysis chamber was maintained at $5 \cdot 10^{-8}$ Pa. The binding energy (BE) scale was regulated by setting the C1s transition at 284.6 eV. The accuracy of BE values was ±0.2 eV.

AFM analysis was performed on a Multimode AFM microscope with a Nanoscope IIIa ADCS controller (Veeco Metrology Group, Cambridge, United Kingdom). A monolithic silicon cantilever (NanoWorld Pointprobe® NCH) with a force constant of 42 N m^{-1}, and a resonance frequency of 320 kHz was used to work on tapping mode. From the analysis of the images, the root-mean-squared roughness (R_{rms}) for the topographic profiles measured on 5 μm x 5 μm images were evaluated.

RESULTS AND DISCUSSION

The results obtained from XPS show a functionalization process due to deposition of polymeric film with important oxygen content. Table 1 shows the results obtained by XPS analysis for PP films treated with CH_4-O_2 plasma for different exposure times. The oxygen content increases with the exposure time, while the nitrogen content remains constant, thus the O/C atomic ratio increases with the exposure time up to 60 s, indicating the high oxygen content in the deposited layer obtained by plasmapolymerization process. The N/C atomic ratio keeps constant, indicating that does not participate in a significant way.

Table 1. Composition of PP film surface (% atomic) obtained with XPS analysis as a function of exposure time.

Exposure time (s)	% atomic C	% atomic O	% atomic N	ratio O/C	ratio N/C
0	92.3	4.0	3.7	0.04	0.04
15	87.3	8.9	3.8	0.10	0.04
39	89.1	6.7	4.2	0.08	0.04
60	85.1	11.1	3.8	0.13	0.04

Figure 1 shows the variation of the surface topography by mans of the 3D representation of PP film untreated and treated with plasma-oxygen plasma for different exposure times. Important changes on the roughness have no detected by atom force microscopy, and thus can be deduced that the main mechanism on the PP surface is the plasma-polymerization that promotes an increase in the polarity of the PP surface and resulting an increase in the wettability of the film.

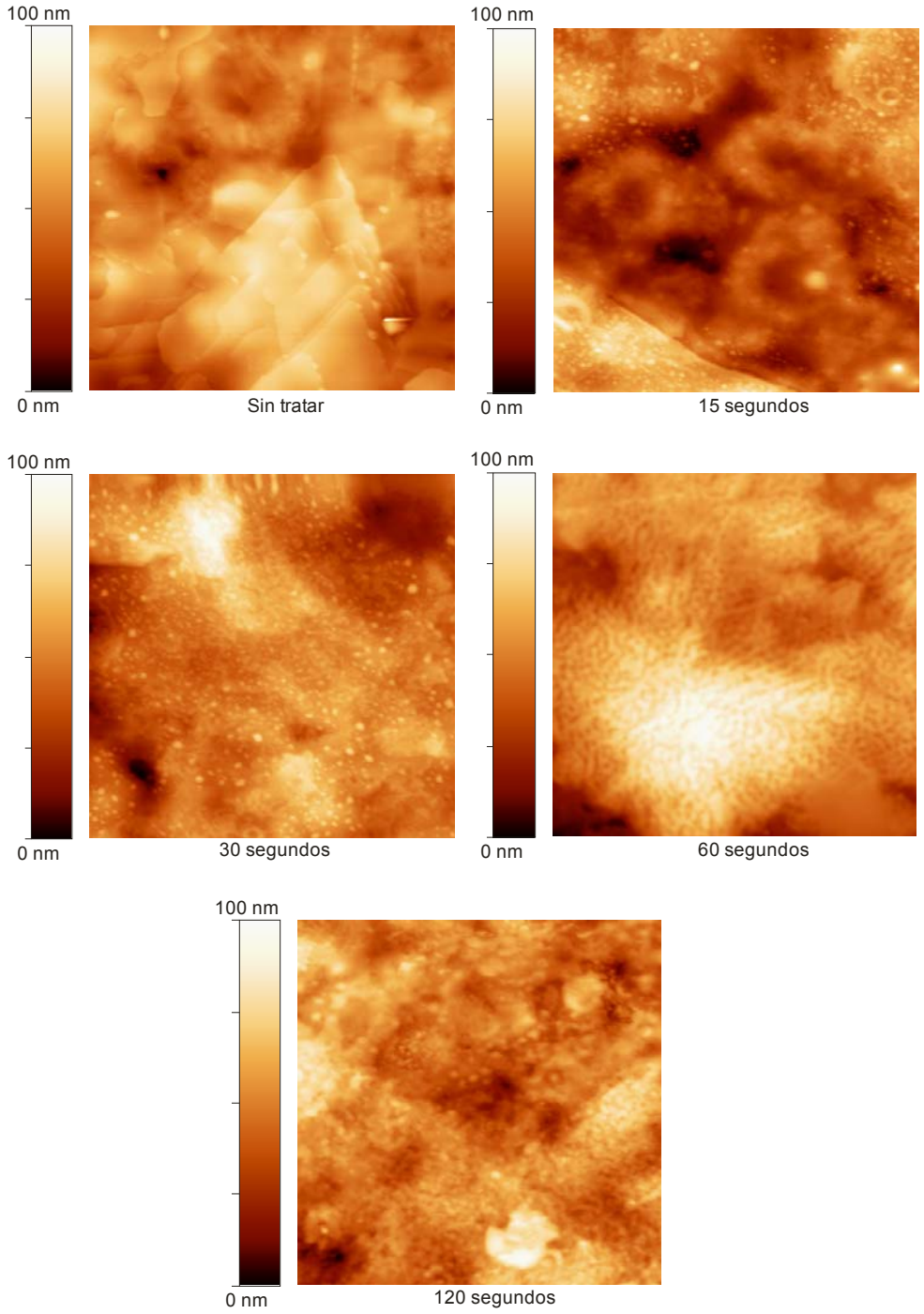

Figure 1. AFM 3D representation of the surface topography (5μm x 5μm) of CH_4-O_2 plasma-treated PP film for different exposure times: a) untreated; b) 30 s; c) 60 s; d) 120 s.

Table 2 shows the root-means-squared roughness (R_{rms}) determined by AFM of PP film treated with CH4-O2 plasma for different exposure times. The values of R_{rms} remain constant as the exposure time increases despite the changes observed in AFM figures. This fact is due to the lower height of the peaks that appears as a consequence of the plasma treatment, thus the CH_4-O_2 plasma-treatment increases the peak number but decreases the peak height, and as a result the roughness remains almost constant.

Table 2. Root-means-squared roughness values determined by AFM analysis of CH_4-O_2 plasmatreated PP film for different exposure times (scale: 5μm x 5μm).

Tiempo de exposición [s]	R_{rms} [nm].
0	12.55
15	12.33
30	14.08
60	13.25
120	13.23

CONCLUSIONS

In this work we have used low pressure plasma with a gas based on methane and oxygen mixture to improve wettability and durability of a PP nonwoven fabrics.. Temperature is a critical factor since the "hydrophobic recovery" process is governed by the diffusion laws. The obtained results show good durability of the plasma-treated polypropylene with the use of methane 80-oxygen 20 plasma gas. The effects of the plasma are similar to a plasmapolimerization process but in this case we obtain hydrophilic properties. The surface does not suffer important changes and the roughness of the material remains constant

Acknowledgement: Authors thank "Ministerio de Ciencia y Tecnología", Ref: DPI2007-66849-C02-02 for financial support.

REFERENCES

1. D. L. Cho, C. N. Choi, H. J. Kim, A. K. Kim and J. H. Go, *J. Appl. Polym. Sci.* **82**, 839-846 (2001).
2. Q. F. Wei, Q. Li, X. Q. Wang, F. L. Huang and W. D. Gao, *Polym. Test* **25**, 717-722 (2006).
3. M. R. Yang, K. S. Chem, J. C. Rsai, C. C. Tseng and S. F. Lin, *Mater. Sci. Eng. C-Biomimetic Supramol. Syst.* **20**, 167-173 (2002).
4. H. S. Choi, V. V. Rybkin, V. A. Titov, T. G. Shikova and T. A. Ageeva, *Surf. Coat. Technol.* **200**, 4479-4488 (2006).
5. H. Demir, D. Balkose and S. Ulku, *Polym. Degrad. Stabil.* **91**, 1079-1085 (2006).
6. C. C. Wang and C. C. Chen, *J. Appl. Polym. Sci.* **98**, 391-400 (2005).
7. H. Y. Yu, Y. Xie, M. X. Hu, J. L. Wang, S. Y. Wang and Z. K. Xu, *J. Membr. Sci.* **254**, 219-227 (2005).
8. S. Nowak, H. P. Haerri, L. Schlapbach and J. Vogt, *Surf. Interface Anal.* **16**, 418-423 (1990).
9. K. S. Chen, J. C. Rsai, C. W. Chou, M. R. Yang and J. M. Yang, *Mater. Sci. Eng. C-Biomimetic Supramol. Syst.* **20**, 203-208 (2002).
10. Y. J. Hwang, M. G. McCord, J. S. An, B. C. Kang and S. W. Park, *Text. Res. J.* **75**, 771-778 (2005).
11. M. M. Radetic, D. M. Jocic, P. M. Jovancic, Z. L. Petrovic and H. F. Thomas, *Environ. Sci. Technol.* **37**, 1008-1012 (2003).

12. Y. Shin, K. Son, D. Il Yoo, S. Hudson, M. McCord, S. Matthews and Y. J. Whang, *J. Appl. Polym. Sci.* **100**, 4306-4310 (2006).
13. J. Verschuren, P. Van Herzele, K. De Clerck and P. Kiekens, *Text. Res. J.* **75**, 437-441 (2005).