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Advantages and Disadvantages of Plasma Treatment of Textile Materials

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Abstract: In the past 25 years we have focused our attention on plasma treatment of textile materials at the University of Wisconsin Madison. This presentation will cover the overview of some of these efforts. In particular, plasma treatments of textile materials to improve properties such as resistance to flame, water repellency, hydrophobicity, and dye-ability will be discussed. These improvements were achieved using both vacuum and atmospheric plasma pressure. The treated samples were analyzed using various scientific tools such as IR, FTIR, ESCM and ESCA. The desired end-use properties or the efficiency of each treatment was measured by the procedures recommended by the AATCC or ASTM technical manuals. Although Plasma treatment provides a unique opportunity for textile treatment, there are many advantages and disadvantages in comparison to the conventional wet processing of textiles.

Keywords: Plasma treatment, Flammability, Wettability, Dyeabilty, Hydrophobicity, Metal deposition, Textiles

The textile industry not only is one of the most energy intensive industries, but also uses tremendous amounts of chemicals and water in textile processing. In addition, it generates a lot of air pollution, which results in a big carbon footprint. Cold Plasma (glow discharge) has opened up many new possibilities for numerous industries including textiles. It is the major electrical discharge used in plasma treatment of textiles. These treatments include but are not limited to improving dyeability, printability, flammability, wettability, hydrophobicity, adhesive binding, and stain and soil resistance. It has also been used for surface functionalization to immobilize active molecules such as enzymes. We have published the results of these investigations in various journals. The following are summeries of a few examples.

The surfaces of PP fabrics were functionalized with Ar and O_2 plasma [1]. Presence of C=O, O-C=O and C-O linkages were detected by survey and high resolution photoelectron spectroscopy and by attenuated total reflectance of treated and untreated fabrics. These tests also indicated that both Ar and O_2 plasma highly oxidized the surface. The RF power, gas flow rate, and treatment time affected the concentrations and the relative ratios of the species. A sharp decrease in dynamic contact angle of untreated fabrics from 120^o to less than 40^o indicated that surface wettability was significantly improved.

Acrylonitrile RF-cold plasma was used to improve water uptake and dyeability of polypropylene fabrics and films [2]. The successful grafting of polyacrylonitrile onto the PP fabric was confirmed using IR and FTR-IR. Longer treatment time and higher power resulted in an increased deposition rate which resulted in a significant increase in water uptake (from 0 to 17mg/cm^2). K/S values were used to assess the dyeability of treated and untreated fabrics. The K/S values of the treated fabrics increased 7 times (from 0.6 to 4.25). These K/S values show successful surface dying of PP fabrics.

Depositing thin metal layers on fabrics is highly desirable for some textile applications, i.e. for altering electrical and optical characteristics. This motivated us to deposit tin-containing polymers from tetramethyltin HF plasma onto PP fabrics and films [3]. The tetrametyletin plasma treated fabric exhibited different morphological appearances. The treated fabrics were metal like, mirror like, transparent or colored. The type of the morphology was related to power, pressure, treatment time, and flow rate. These parameters need to be studied further in order to properly establish the plasma parameters for the desired morphology.

Surface of PP fabric samples were treated with Hexamethyledisiloxane (HMDSO) to produce inorganic protective layers to reduce wettability [4]. All HMDSO plasma treated fabrics showed a significant decrease in demand wettability (water uptake) and a significant increase in contact angle values. Presence of Si-O-Si and Si-C based structures were confirmed using ATR-IT, FTIR and ESCA.

Polypropylene films were plasma treated using carbontetrafluoride [5]. Survey ESCA showed that fluorine (57-60%) and carbon atoms (37-39%) were detected on the treated materials. Potential applications for this work are stain and soil resistance, and those end-uses that a Teflon-like thin layer is needed.

Every year thousands of people are injured by textile fires in the US. The total loss caused by fires in the USA alone is approximately $250 billion, which is the equivalent of approximately 2% of the country's GDP [6]. Protecting critical infrastructures, especially those that are vital to public health and safety, preventing loss of lives and losses due to property damage, and safety of the first responders, firefighters, soldiers, etc. is a major and challenging task for homeland security. Therefore, reducing flammability of textile materials has been an important goal for textile industry. Flame resistance (FR) fabrics are used in many products such as upholstered furniture, home furnishing, transportation, curtaining, and children's sleepwear. However, the safety and environmental effect of some of these FR chemicals are questionable. In this research [7,8]Sodium silicate layers were pre-deposited onto viscose and cotton flannel substrates and grafted/crosslinked using atmospheric pressure plasma. The plasma treated fabrics were tested with a 45^o flammability test chamber. The results showed a significant improvement in their flame-retardant properties. The flame spread time increased from 9 seconds to 30 seconds. The TGA and DS analysis showed enhanced thermal stability. The presence of SiO_2 networks were confirmed by XPS and SEM. The treated substrates had significant flame retardant properties even after intense ultrasound washes.

Working in the field of textile chemistry is challenging due to the high use of energy and water, and the large diversity and number of chemicals. Although plasma chemistry opens up new opportunities, it has a lot of disadvantages as well. Therefore, one must carefully assess all advantages and disadvantages of both conventional wet processing and plasma chemistry before investing or selecting one process over the other. The followings are a few advantages and disadvantages of these processes.

Advantages

In comparison to the conventional textile wet processing, plasma treatment of textiles has many advantages such as:

1. Endless chemical modifications are possible by choosing appropriate gasses or chemicals.

2. In most cases it can be a dry process, reducing water consumption and energy to dry the treated materials.
3. Reduction in the amount of water usage results in reducing the amount of waste water and the waste water treatment cost.
4. It has an economical advantage over the conventional wet processing due to its low chemical consumption and reduction in chemical and water costs.
5. Although for the above reasons all plasma processing is more environmentally friendly in comparison to the textile wet processing, the closed plasma treatment systems are an even more environmentally friendly process because the plasma byproducts can be trapped rather than being released into the environment.
6. Pore-free, uniform thin films with superior properties that can't be achieved with conventional chemistry can be deposited on almost any substrate.

Disadvantages

1 System dependency is one of the most important disadvantages of the plasma treatment. This means that the same flow rate, gas pressure and power input may not produce the same level of the needed reacting species.

2 Although initial investments such as purchasing expensive plasma equipment and high vacuum pumps are considered to be limiting factors and could be considered as a disadvantage, these costs can be recovered by savings that were mentioned above.

3 Scaling up and converting pilot batch process into a continuous process could also present some technical challenges.

4 Optimal process parameters must be established for each process and equipment. However, it is not too difficult to overcome these challenges.

5 Treating thin surface layers without changing the bulk could also be a disadvantage for some end-use and an advantage for when the objective is to keep the bulk untreated and only thin surface treatment is needed.

6 Textile materials are made from yarns or directly from fibers. In either case the fibers are covering each other, especially when they are in high twist yarns. This creates a shadow effect and the shadowed areas are generally protected from plasma treatment.

7 It is harder to predict the exact structural characteristics of the plasma treated area for a more complex molecule. This is due to the fact that plasma causes the complex molecular structure to fragment into a multitude of coexisting active species which could react or deposit on the surface.

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References

[1] Plasmas and Polymers, 2, 3, (1997)

[2] Textile Research J., 63, 12, (1993)

[3] J. of Applied Poly Science, 55, (1995)

[4] European Polymer Journal, 31, No. 9, (1995)

[5] Polymer Bulletin,43, No. 4, (1999)

[6] http://www.ceresana.com/en/html/flame_retardants.html

[7] Journal of Applied Polymer Science, 124, 1, (2011)

[8] Journal of Applied Polymer Science, 117, 1, (2010)