Inkjet printing and plasma in the digital fashion concept

Inkjet tisak i plazma u konceptu digitalne mode

Review paper / Pregledni rad

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Abstract

Advanced technologies in the textile industry and the concept of digital fashion have changed the way clothing is designed, produced and consumed. Digital fashion, the result of this combination of technological innovations, is becoming omnipresent and offers a number of benefits. Design adaptability is a key element of digital fashion. Thanks to digital printing, inkjet technology and plasma surface modification, designers and manufacturers have more freedom to create different patterns and designs. With these tools, prints and shapes can be precisely applied to fabric, making it easier to customise clothing to meet customer's unique needs and preferences. Fast production is also a feature of digital fashion. Digital printing processes combined with plasma surface modification eliminate the need for time-consuming material preparation processes and chemical treatments. This significantly speeds up production and shortens product development time. Sustainability is becoming increasingly important in the fashion industry, the use of plasma and environmentally friendly surface modification methods reduces the environmental impact of the textile industry. Reducing waste and the need for large inventories, helps conserve resources and reduce the negative impact on the environment. Advanced technologies such as digital printing and the use of nanotechnology enable the production of garments with advanced features such as water resistance, antibacterial properties and reflective surfaces. All this makes digital fashion a combination of aesthetics, functionality and environmental responsibility. This concept meets the demands of the modern consumer who is looking for personalization, quick availability, high quality and environmental protection in the fashion industry. Digital fashion is thus becoming the future of the fashion industry, harnessing technology to create innovative, sustainable and adaptable products.

Keywords: inkjet printing; plasma; digital fashion; advanced technologies

Sažetak

Napredne tehnologije u tekstilnoj industriji i koncept digitalne mode promijenili su način na koji se odjeća dizajnira, proizvodi i konzumira. Digitalna moda, rezultat ove kombinacije tehnoloških inovacija, postaje sveprisutna i nudi niz pogodnosti. Prilagodljivost dizajna ključni je element digitalne mode. Zahvaljujući digitalnom tisku, inkjet tehnologiji i modifikaciji površine plazmom, dizajneri i proizvođači imaju više slobode u stvaranju različitih uzoraka i dizajna. Pomoću ovih alata, otisci i oblici mogu se precizno prenijeti na tkaninu, što olakšava prilagođavanje odjeće kako bi zadovoljila jedinstvene potrebe i preferencije kupaca. Postupci digitalnog tiska u kombinaciji s modifikacijom površine plazmom eliminiraju potrebu za dugotrajnim procesima pripreme materijala i kemijskim tretmanima. To značajno ubrzava proizvodnju i skraćuje vrijeme razvoja proizvoda. Održivost postaje sve važnija u modnoj

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industriji, korištenje plazme i ekološki prihvatljivih metoda površinske modifikacije smanjuje utjecaj tekstilne industrije na okoliš. Napredne tehnologije kao što su digitalni tisak i korištenje nanotehnologije omogućuju proizvodnju odjevnih predmeta s naprednim značajkama kao što su vododbojnost, antibakterijska svojstva... Sve to čini digitalnu modu spojem estetike, funkcionalnosti i odgovornosti prema okolišu. Ovaj koncept zadovoljava zahtjeve modernog potrošača koji u modnoj industriji traži personalizaciju, brzu dostupnost, visoku kvalitetu i zaštitu okoliša. Digitalna moda tako postaje budućnost modne industrije, koristeći tehnologiju za stvaranje inovativnih, održivih i prilagodljivih proizvoda.

Ključne riječi: inkjet tisak; plazma; digitalna moda; napredne tehnologije

1. Introduction

Wettability is one of the basic properties of materials intended for printing, which depends on the chemical composition and morphology of the material, which in turn affects the hydrophilicity and quality of the print. Modification of the surface layer of the polymer is carried out to change the hydrophilicity of the material, increase its surface free energy, create new functional groups, change the surface morphology, roughness and cross-linking, as well as to remove impurities or, in the case of medical polymers, to sterilize or improve biocompatibility. Activation can be achieved by physical or chemical methods [1]. The former are considered more environmentally friendly as they do not require chemical solutions. Physical activation methods include corona, plasma, flame, laser, ultraviolet, X-ray and high-energy electron beam activation. Corona activation is a common industrial method due to the low cost and high efficiency of the process as well as the possibility of application directly in the production line. However, plasma treatment allows greater uniformity in the modification of the surface layer of the material. In addition, plasma activation is more efficient than corona activation, it enables a greater increase in surface free energy [1-7].

2. Plasma

A totally or partially ionized gas made up of electrons, ions, radicals, and high-energy neutrals is called plasma. It is considered the fourth aggregate state, which is the largest part of the matter of the universe [1, 2, 8, 9]. The capacity to apply plasma to any kind of material and the potential to get functional features without changing the fundamental properties of the textile material or having any negative environmental effects are its two key advantages. Since handling hazardous chemicals is not a part of plasma treatment, there are fewer chemical requirements for wet treatment following plasma treatment than with chemical treatments, and effluent issues are avoided. In addition, the technique can prevent ozone depletion by eliminating volatile organic compounds, controls pollution by having low emissions, and is safe for aquatic flora and fauna because there is no waste water generation [2-6, 8-12]. Numerous industries, including textiles, electronics, the automotive sector, medicine, etc., have used plasma technology. Plasma technology can also be used for various targeted surface effects, such as hydrophilicity, hydrophobicity, and adhesion, depending on the type of gas or gas mixture used and other processing parameters. Gases such as oxygen, air, nitrogen and argon can be used to improve the surface free energy, but on the other hand, gases such as fluorocarbons are polymerizing plasma gases that can be used to produce a hydrophobic surface [4]. The effects of the modifications we hope to accomplish, the costs we can afford, and the efficiency of the necessary process all play a major role in the type of plasma we choose. There are benefits and drawbacks to every kind of plasma, including atmospheric and low-pressure plasmas [1]. One of the most effective methods for altering a material's surface is low-pressure plasma processing, which is also safe and cost-effective from an environmental and financial standpoint. Targeted surface modifications, such as wettability, hydrophobicity, printability, dyeability, antimicrobial performance, flame retardant and adhesion properties, sterilization, antistatic properties, UV protection, etc., are among the numerous textile applications for which it is extensively used [4, 13].

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Increasing the material's hydrophilicity is crucial to getting it ready for printing or other decorative processes. A decrease in C-C and C-H bonds and an increase in free radicals are indicative of changes in the surface polymer layer's chemical composition. The material's surface produces new functional groups. Polymer surface ablation, or surface destruction, is the outcome of intricate processes that occur when the material is exposed to plasma. During the activation process, components of the plasma react with the polymer chain, altering the surface properties and causing polymer degradation. Cross-linking may happen, and the top polymer layer (such as PLA and PP) produces low molecular weight and gaseous products. The gravimetric analysis method can be used to find the ablation rate. Eliminating weak domains and raising surface roughness are crucial for ablation because these factors greatly affect how well paint adheres to substrate, how strongly laminate bonds, etc. [1].

3. Plasma effects on the textile surface and its impact on digital printing

Plasma can be used to improve the print's qualities after it has been printed or to alter the surface before printing. In the first instance, it must enhance the substrate's printing qualities and permit high-quality printing, just like conventional corona activation. In contrast, the second scenario aims to achieve or enhance the printed image's usability. The plasma activation used before the printing process is primarily intended to improve the hydrophilicity of the substrate and can be performed using gases such as He, Ar, N_2, NH_3 and O_2, etc. Furthermore, certain kinds of plasma, like Ar, have the ability to drastically alter the substrates' roughness [1, 5].

The ion bombardment of the surface causes physical sputtering and chemical reactions of reactive plasma species. These reactions can result in: (a) cleaning of the surface in which the unwanted surface contamination is volatilized and removed; (b) activation, an enhancement of the surface energy by the generation of chemically reactive sites on the textile surface; (c) etching of the surface caused by the chemical reaction of plasma reactive species with active substrate groups which are desorbed from the surface and carried away from the substrate; and (d) coating or plasma polymerization using reactive and polymerizable gases which create a functional thin film on the textile surface (Figure 1.).

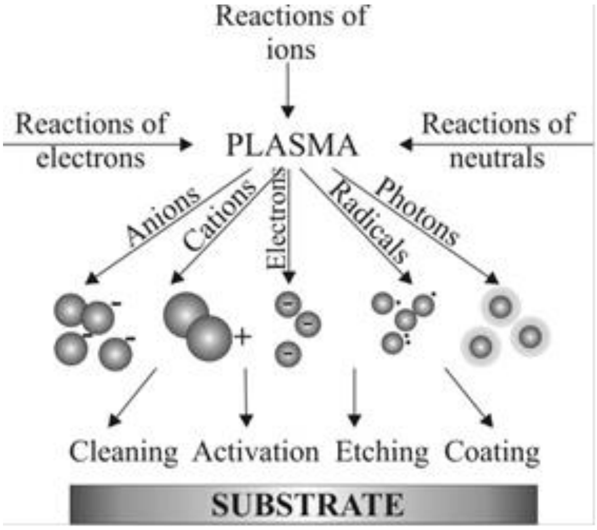

Figure 1. Plasma–substrate interactions [5]

The basic test parameters for determining the influence of activation on the surface layer of the polymer are the measurement of the contact angle with water or extended with other measuring liquids. Determining the surface free energy value requires knowledge of the contact angles of a minimum of two liquids. Energy dispersive X-ray spectrometers, X-ray photoelectron spectroscopy, and Fourier transform infrared spectroscopy can be used to assess chemical changes in the upper layer and identify emerging functional group types. Atomic force microscopy (AFM), optical microscopy, and scanning electron microscopy (SEM) are used to analyze the changes in surface morphology. The adhesion and wettability of the material are impacted by changes in surface roughness, which can also be found out via AFM measurements. Occasionally, assessments are conducted on variations in dynamic mechanical thermal properties, polymer crystallinity, elongation and tensile strength, material barrier properties, etc. [1, 3-8, 10, 12, 17-20].

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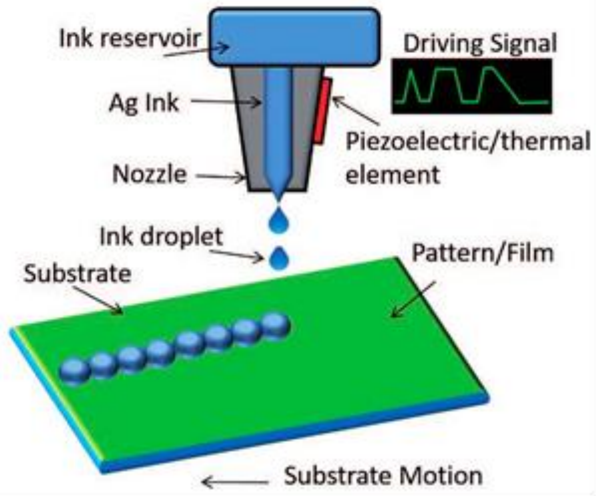

Figure 2. Schematic illustration of inkjet printing technology [18]

Inkjet is a digital printing technique that can be used for printing on all types of substrates, including various textile materials of different structures and shapes [2, 6, 14]. Inkjet technology uses less water, energy, chemicals, and waste than traditional production techniques like finishing and screen-printing [14, 15]. Advantages of inkjet printing on textile products include production purity, design pattern creativity, and flexibility [16]. Digital inkjet printing technology has demonstrated greater potential than traditional textile printing techniques due to its efficiency. These possibilities include superior sample quality, substantially reduced pollution, fast response to frequent changes in the textile market, and lower overall printing costs [13, 14, 17]. Additionally, inkjet printing makes possible visual effects that screen printing is not practical for, like tone transitions and infinite patterns for repeating sizes [12]. On figure 2 the schematic illustration of inkjet printing technology is shown. Digitally printed material and clothing from a fashion show is shown in Figure 3.

3.1. Cotton

In order to improve the quality of digital inkjet printing, the influence of low-pressure plasma processing on cotton knit samples was examined [6]. Cotton fabric was pretreated in one study using atmospheric pressure plasma that included helium and oxygen gas plasma for three seconds. Following that, before inkjet printing, the treated fabric was separately treated with chitosan, sodium alginate, and a paste made of chitosan and sodium alginate. A mixture of sodium alginate and chitosan gives better color values, fastness properties and antibacterial functionality with plasma treated fabric samples compared to untreated samples. In improved grooves on the fiber surface, shrinkage and cracks were observed in plasma treated cotton fabric samples under a scanning electron microscope. This enables a larger application of printing paste [4, 17]. The higher absorption of the resulting fabric can thus be attributed to the increase in polar functional groups. Comparing the untreated cotton fabric to the fabric treated with plasma, the surface contact angle decreased from 98° to 58° and the wetting time decreased from 6.3 to 4.5 seconds, suggesting that the plasma treatment greatly enhanced the fabric's wetting ability [4].

3.2. Wool

The wool fiber has a complex structure and surface morphology. Chemically, about 80% of wool consists of keratin proteins, which are condensed amino acids. The structure of the wool fiber consists of the outer cuticle layer (10%) and the inner cortex (85%). Scaly cuticle consists of epicuticle, exocuticle and endocuticle. The epicuticle is predominantly hydrophobic keratin

Figure 3. Digitally printed material and clothing from a fashion show [21, 22]

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and lipids which affects on absorption during subsequent dyeing and printing processes. Chlorination is the conventional process used to remove epicuticles, but it is not environmentally friendly [8]. As a result of the oxidation of the hydrocarbon chain by the application of plasma on the wool fibers, new hydrophilic groups such as –OH, –C=O and –COOH develop on the surface. The fatty acid chain length is also shortened, which enhances fiber cohesiveness, shrinkage resistance, weight fastness, and dyeing ability. In the exocuticle, the oxidation process also increases cysteine's oxidation, converting it to cystic acid and lowering the degree of fibrous plate cross-linking. Hence, plasma therapy alters the endocuticle complex and cell membrane, gets rid of the fatty acid layer that is covalently bound, and partially destroys the epicuticle. It was discovered that subjecting yarn to an oxygen plasma treatment for five minutes increased surface roughness. Wool fiber absorbency was enhanced by improved grooves brought about by shrinkage [2, 8].

3.3. Silk

Air plasma from the atmosphere is used to treat the silk's surface before it is used as an inkjet printing substrate. Consequently, the contact angle measurement showed a significant increase in the wettability of the silk fabric surface. A higher K/S value and a distinct print edge further demonstrated the superior properties of inkjet printing on silk. Experiments on the aging process on color strength and chemical composition demonstrate that while the surface property of silk fabric deteriorates over time during storage, it never completely recovers. As can be seen from the above, printing on silk fabrics can perform better and have better surface qualities when using atmospheric pressure plasma. The best results from ink-jet printing appear 24 hours after plasma treatment [7]. As a result of improved surface properties, printing directly on the fabric shows a clear print edge and a greater depth of coloration. Apart from atmospheric plasma, it has been verified that atmospheric multiple ambient gas plasma is also a highly efficient method for enhancing physico-morphological and chemical properties, thereby augmenting the printing performance on silk fabrics. The modified silk substrates are more hydrophilic than the unmodified ones, according to the contact angle measurement. To assess the qualities of direct printing on the fabric, tests were conducted on the spill resistance and color strength. The modified sample has a deeper color, a darker shade, and a higher saturation, according to a study of color intensity [19].

3.4. Polyethylene terephthalate, PET

The most affordable and widely used method in the industry for significantly increasing wettability is alkaline (sodium hydroxide) based PET hydrolysis, though it uses a lot of chemicals, water, and energy and may harm mechanical and aesthetic qualities in some situations. Although enzyme-based treatments (like cutinase) are a little more costly, they can greatly increase the wetting capacity while having less of an effect on the resources and physico-mechanical characteristics of PET fibers. Although it requires a relatively larger initial investment, atmospheric plasma can improve on the alkaline method in a similar way with less impact on mass properties and resource consumption [2, 12, 15]. The pretreatment results showed that, compared to alkaline and enzyme-based processes (cutinase), air-atmospheric plasma treatment can improve the wettability of PET without compromising other important physical properties [15].

SEM photographs show that the surface of the plasma-treated fibers becomes rougher than the surface of the untreated fibers. The roughness effect on the fabric's surface is thought to be the result of etching and ablation on the substrate caused by the plasma treatment. Measurements of contact angles show that plasma treatment reduced contact angles in comparison to the untreated sample. Furthermore, after plasma modification, the mechanical property results do not indicate a discernible decrease in breaking strength and breaking elongation in the warp and weft directions [10].

The oxygen plasma increased the number of polar groups on the polyester surface and roughened the fabric's surface. Following treatment with oxygen plasma, the treated fabric's contact angles decreased to zero degrees, indicating the phenomenon of expansion and suggesting the possibility of increasing the fabrics' hydrophilicity. A higher color yield is a result of the plasma treatment's increased surface roughness [17].

4. Conclusions

Plasma surface modification, as one of the most effective and economical surface treatment techniques, is widely used in the textile industry for fabric surface modification and activation. The review demonstrated that inkjet printing of textile substrates that had undergone plasma treatments in a brief amount of time increased in wettability and improved in quality. The effect of increasing the polar functional groups C-O, C=O, and O-C=O was observed in various fabric substrates, including polyester, silk, cotton, wool, and others. Print sharpness, color fastness and functional properties for treated fabrics are improved. In general, plasma surface modification has facilitated the inkjet printing process. It can be concluded that the application of environmentally friendly technologies, plasma and digital inkjet printing, is essential for the development of sustainable materials and the sustainability of textile technology in order to reduce environmental pollution and the generation of unnecessary waste. Due to new demands on the market, the textile industry itself must develop new solutions with the aim of shortening product manufacturing time while increasing the level of quality and reducing the impact on the environment. Due to its efficiency, digital printing technology is increasingly used in the textile and fashion industry.

References

[1] Izdebska-Podsiadły J.: Application of Plasma in Printed Surfaces and Print Quality, In Non-Thermal Plasma Technology for Polymeric Materials, Woodhead Publishing, Elsevier 2019, 159-191

[2] Hamdy D.M., Osman H.A., Hassabo A.G.: A Recent Uses of Plasma in the Textile Printing, Journal of Textiles, Coloration and Polymer Science **19** (2022) 1, 1-10

[3] Ercegović Ražić S., Čunko R.: Modifikacija svojstava tekstilija primjenom plazme, Tekstil **58** (2009) 3, 55-74

[4] Madhukar Thakker A., Sun D., Siddiqui M.O.R.: Inkjet printing of textiles enhanced by sustainable plasma technology, In Digital Textile Printing, Woodhead Publishing, Elsevier 2023, 137-155

[5] Peran J., Ercegović Ražić S.: Application of atmospheric pressure plasma technology for textile surface modification, Textile Research Journal **90** (2020) 9-10, 1174-1197

[6] Ercegović Ražić S., Glogar M.I., Drakula N.: Plasma and digital ink jet – green technologies for improvement durability and sustainability of functionalized cotton knitwear, Proceedings of Nature inspired sustainable solutions, ICNF 2023, Madeira Portugal 2023, 234-235

[7] Zhang C. et al.: Surface processing and ageing behavior of silk fabrics treated with atmospheric-pressure plasma for pigment-based ink-jet printing, Applied Surface Science **434** (2017), 198-203

[8] Madhukar Thakker A., Sun D., Bucknall D.: Inkjet printing of plasma surface–modified wool and cotton fabrics with plant-based inks, Environmental Science and Pollution Research **29** (2022), 68357-68375

[9] Khaled E. et al.: Plasma Technique for Modification of The Natural Thickener to Improve Textile Printing Performance, Journal of Textiles, Coloration and Polymer Science **20** (2023) 2, 333-358

[10] Zhang C., Zhang X.: Nano-modification of plasma treated inkjet printing fabrics, International Journal of Clothing Science and Technology **27** (2015) 1, 159-169

[11] Biswas T.T., Yu J., Nierstrasz V.A.: Piezoelectric inkjet printing of tyrosinase (polyphenol oxidase) enzyme on atmospheric plasma treated polyamide fabric, Scientific Reports **12** (2022), 6828

[12] Zhang C., Fang K.: Surface modification of polyester fabrics for inkjet printing with atmospheric-pressure air/Ar plasma, Surface & Coatings Technology **203** (2009), 2058-2063

[13] Ercegović Ražić S. et al.: Plasma pre-treatment and digital ink jet technology: A tool for improvement of antimicrobial properties and colour performance of cellulose knitwear, Materials Today **31** (2020) 2, 247-257

[14] Kumelachew D.M., Wagaye B.T., Adamu B. F.: Digital textile printing innovations and the future, In Digital textile printing, Woodhead Publishing, Elsevier 2023, 241-259

[15] Biswas T., Yu, J., Nierstrasz V.: Effective Pretreatment Routes of Polyethylene Terephthalate Fabric for Digital Inkjet Printing of Enzyme, Advanced Materials Interfaces **8** (2021), 2196-7350

[16] Özgüney A.T. et al.: Inkjet Printing of Linen Fabrics Pretreated with Atmospheric Plasma and Various Print Pastes, AATCC Journal of Research **4** (2017) 1, 22-27

[17] Pransilp P. et al.: Surface modification of cotton fabrics by gas plasmas for colorstrength and adhesion by inkjet ink printing, Applied Surface Science **364** (2016), 208-220

[18] Uddin J. et al.: Thermal Inkjet Printing: Prospects and Applications in the Development of Medicine, Technologies **108** (2022), 1-29

[19] Zhang C. et al.: Study on the physical-morphological and chemical properties of silk fabric surface modified with multiple ambient gas plasma for inkjet printing, Applied Surface Science **490** (2019), 157-164

[20] Ercegović Ražić S. et al.: Durability assessment of digital pigment inkjet printing on plasma pretreated natural leather for car interior design, Proceedings of International Textile & Fashion Congress (ITFC 2023), Istanbul 2023, 235-241

[21] https://print-magazin.eu/dvije-uspjesne-price-o-suradnji-modne-i-graficke-industrije/, Accessed: 2023-11-10

[22] https://textilelearner.net/leather-printing-techniques-step-by-step/, Accessed: 2023-11-10

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