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# A New Eco-friendly Approach for Fabrication of Electrically Conductive and Antibacterial Polyamide Yarns

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**ABSTRACT**

In this paper, an environmentally friendly method to produce electrically conductive and antibacterial silver nanoparticles (AgNPs) coated polyamide (PA) yarns was reported. A new AgNPs coated composite PA yarn has been synthesized in the presence of carboxy methyl starch (CMS) reducing agent. Silver nitrate (AgNO3) was reduced on the surface of the PA fibers which allowed formation of silver nanoparticles. Scanning electron microscopy (SEM) images indicated distribution of silver nanolayer formation on the composite fiber surface. Electrical conductivity of composite yarns was measured by four point probe technique and was changed from 1.015x10-5 to 1.282x100 S/cm. The ecofriendly coating method used in this study enabled to produce multifunctional composite PA yarns with antistatic and antibacterial properties.

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**KEYWORDS**

Silver nanoparticles, conductivity, polyamide yarn, carboxy methyl starch

## 1. INTRODUCTION

Increasing the awareness towards green chemistry and other biological processes evoked the interest to develop an eco-friendly approach for the synthesis of nanoparticles which has several advantages such as simplicity, cost effectiveness, compatibility for textile application as well as for large scale commercial production [1-5]. Utilization of nontoxic chemicals, environmentally benign solvents and renewable materials are some of the key issues that merit important consideration in a green synthesis strategy. Nanocomposites are used in many applications such as medical textiles, cosmetics, agriculture, optics, food packaging, semiconductor devices, aerospace, construction and catalysis. New properties are imparted to textiles using nanotechnology such as anti-bacteria, UV-protection, anti-static, improvement of dye ability, flame retardency, water repellency, soil resistance and wrinkle resistance [3]. There are various materials used in the production of multifunctional nanocomposite textiles. The AgNP is a well-known effective antibacterial agent, which is commonly used in commercial products including in the textile industry to avoid microbial contamination. Nowadays, silver nanoparticles (AgNPs) are increasingly used in various fields such as medical device coatings, food industry, health care, protective clothing, medical textiles, optical sensors, cosmetic product, seat covers. Silver nanoparticles easily interact with other particles due to their physical, chemical, thermal, optical, high electrical conductivity and biological properties [6-11]. Biologically-mediated synthesis of nanoparticles have been shown to be simple, cost effective, dependable, and environmentally friendly approaches. Several studies reported the synthesis of AgNPs using green, cost effective, and biocompatible methods without the use of toxic chemicals in biological methods. Compared to chemical methods, biological methods allow for more ease in the control of shape, size, and distribution of the produced nanoparticles by optimization of the synthesis methods, including the amount of precursors, temperature, pH, and the amount of reducing and stabilizing parameters [11, 12]. The present study involves the incorporation of silver nanoparticles on polyamide fibres by “green synthesis strategy”. The advantages of this process are: (a) no need to have extra reducing agent(s), (b) the process can be conducted at room temperature, under normal pressure in aqueous solution,

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and (c) finally the developed silver nanoparticles by this process have excellent properties, including long term dispersion stability [1-5].

Polyamide (PA) is the third largest textile fiber consumed in the world, after polyester and cotton. PA-knitted goods are used in underwear, sports and swimwear, stockings and tights, bed linen, car upholstery, nets, and others. Besides, the polyamide textiles with multifunctional properties can be applied in various commercial usages due to good electrical conductivity, light weight, and corrosion resistance along with enhanced mechanical properties [10,13]. In order to obtain a multi-functional yarn with an extremely high improvement in adhesion of silver nanolayer, the polyamide yarn has been chosen as the substrate. Polyamide is an electron-rich and polar synthetic polymer (polyamide) usually made of adipoyl chloride and hexamethylene diamine monomers to form a linear molecular chain[13].

There are various methods to obtain conductive textiles such as the use of conductive agent and particles, metallic fibers, coating with conductive polymers. The use of conductive agents and particles is a cost effective process that has been attracted much attention because of its low cost and fiber structural features do not change. Hasan et al. studied to develop chitosan-mediated green silver nanoparticles for polyester fabric coloration. They developed that a novel route for the coloration of polyester fabric with green synthesized silver nanoparticles using chitosan as a natural eco-friendly reductant and explained that the proposed coating process using green nanoparticles can contribute to low-cost production of sustainable textiles [14]. Gawish et al. investigated that antibacterial and antifungal properties against Staphylococcus aureus, Klebsiella pneumonia and Candida albicans by using standard methods (AATCC TM100). Surface electrical conductivity and color changes are measured for the treated fabrics and they determined nano silver coated polyamide fabric displayed electrical conductivity better than the untreated one [3]. Sang Su et al. fabricated highly conductive graphene/Ag hybrid fibers for flexible fiber type transistors. This fibers have flexible, and electrically conductive textiles are highly suitable for use in wearable electronic applications. They emphasised that exhibited excellent flexibility, high electrical performance and outstanding device performance stability [15]. Montazer et al. studied a new method to produce conductive polyester fabric by using a novel electroless plating of silver nanoparticles. They investigated silver nanowires and cupro fabrics together using a dipping-drying method to prepare highly stretchable electrically conductive textiles [10]. Dong et al. reported the biosynthesis of silver nanoparticles via a single-step reduction of silver ions and emphasized that green synthesis of silver nanoparticles, using hydroxy propyl methyl cellulose and glucose as capping agents and reducing agents respectively, is an environmental friendly, simple and efficient route for synthesis of metallic nanoparticles. By they investigated using HPMC, the effects of the reaction time, temperature, concentration of silver ion, reducing agents on the particle size were investigated and measured AgNP size range from 3 nm to 17 nm according to SEM images [16]. Ahmed H.B., et al studied the silver nanoparticles-carboxy methyl cellulose (AgNPs-CMC) composite prepare by interaction of silver nitrate with CMC using pad-dry-cure method. They found electrical resistance as 172 MΩ after application of 10 CMC layers with excellent antibacterial property [17]. Hebeish A. et al. (2011) investigated that green synthesis of nano sized colloidal silver solution using hydroxypropyl starch (HPS). Also, It has determined the optimum conditions formation of AgNP as temperature, time and concentration on cotton fabrics. A similar approach based on the use of silver nanoparticle is presented by Hebeish A. et al. (2011) In this case, Ag NPs have been prepared using hydroxypropyl starch (HPS) as a reducing agent through green synthesis which reduce silver ions ($Ag^{+}$) to nanoparticles ($Ag^{0}$). In addition, it was determined that optimum conditions as 0.9 g HPS (MS: 0.84), AgNO3; 0.078 g, pH; 12, temperature; 70◦C, duration; 15 min. They determined in the range of 6–8 nm of AgNPs colloids with excellent size and distribution according to SEM images [18].

In this study, an environmentally friendly coating method was introduced to fabricate a multifunctional silver nanoparticle coated composite polyamide yarn with desirable electrically conductivity and antibacterial properties in the presence of carboxy methyl starch reducing agent. The advantage of this method is preparing of AgNPs without any organic solvents or other chemical reducing agents and contributing to sustainable textile production. The composite PA yarns can be used in a wide range of applications such as wound dressings, hygienic clothing and medical applications where the presence of bacteria is hazardous.

## 2. MATERIAL AND METHOD

### 2.1 Material

Polyamide multifilament yarns (technical properties; 70 denier, two ply, 10 filament (70/2/10)) were supplied from Karacasu Textile, Turkey. $AgNO_3$ (>99 %) were purchased from Tekkim Chemicals. Carboxy methyl starch (CMS) was synthesized from potato starch waste in ÜSKİM laboratory by Dolaz et al [19]. Ethanol and acetone were supplied from Sigma Aldrich and were used as received.

### 2.2 Method

#### 2.2.1. Preparation of silver coated polyamide yarns

The silver-coated PA yarn was fabricated by in-situ reduction of silver nitrate. In the first set of optimization studies, the effect of $AgNO_3$ concentration and process time were investigated in the development of silver coated PA yarns (Table 1).

**Table 1.** Coating receipt of AgNPs polyamide yarns

| Sample | $AgNO_3$ Ş (gr) | CMS (gr) | Time (h) |
|---|---|---|---|
| **F025** | 0,25 | 0,05 | 1,2,3,4,5 |
| **F05** | 0,625 | 0,125 | 1,2,3,4,5 |
| **F1** | 1 | 0,2 | 1,2,3,4,5 |
| **F2** | 2 | 0,4 | 1,2,3,4,5 |
| **F5** | 5 | 1 | 1,2,3,4,5 |

Selected concentrations of $AgNO_3$ (i.e.; 0,25 g/100 mL, 0,5 g/100 mL, 1 g/100mL, 2 g/100mL and 5 g/100mL) were dissolved in distilled water at room temperature and PA multifilament yarn was wetted with $AgNO_3$ solution. Then, PA multifilament yarn was treated with prepared CMS solution at room temperature for selected process time and concentration to obtain a thin silver nanolayer formation on the fiber surface.

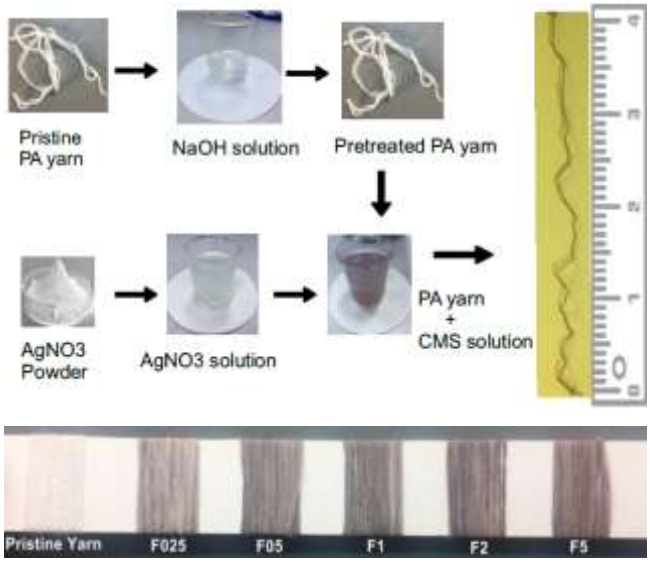


**Figure 1.** Preparation of AgNPs coated composite PA yarn

The color of reducing solution turned light brown to grey depending on time and amount of silver ions. After the reducing process, the PA yarns were rinsed with distilled water and ethanol. At last, the PA yarns were dried in an oven at 60 ºC (Figure 1).

### 2.2.2. Characterization

In order to investigate the formation of silver nanoparticles on the PA fibers, a Carl Zeiss Evo LS10 scanning electron microscope is used with an accelerating voltage of 3 kV. The samples were gold coated and placed on the aluminum stub and observed under vacuum. Energy dispersive X-ray (EDX) measurements for element analysis were analyzed using Carl Zeiss Evo LS10 instrument. A UV/visible spectrometer (Lambda 750, Perkin- Elmer) was also used to investigate the mono dispersity of the nanosilver particles. XRD patterns were obtained using an X'Pert PRD PAN alytical instrument. Thickness of the AgNPs coated PA yarns was measured by Mitutoyo Digimatic Outside Micrometer (MDC-25SB). The direct current (DC) electrical conductivity measurements were carried out by a DC conductivity meter using four point probe method (Entek FPP 510). The antimicrobial activity of AgNPs coated PA yarns was determined by evaluating of inhibition zones after 24 h of incubation at 37 ºC via disc diffusion method. Martindale Abrasion Tester was used to determine the abrasion resistance of PA composiye yarns with ISO 12945-1.

## 3. RESULTS AND DISCUSSION

### 3.1 UV–Vis Spectroscopy

Figure 2 shows the change in color of silver nanoparticle solutions at different $AgNO_3$/CMS concentrations.

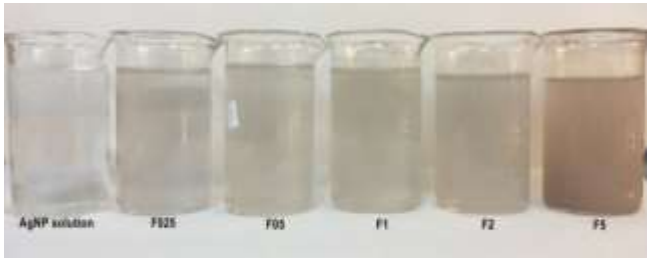


**Figure 2.** Silver nanoparticle coating solutions at different $AgNO_3$/CMS concentrations.

It is observed that the color of the colloid solutions were increasingly changed grey to purple with the increasing of $AgNO_3$/CMS concentration (Figure 2). Figure 3 presents UV–visible spectra of the AgNPs colloid solutions which were obtained in the wavelength range 200–600 nm.

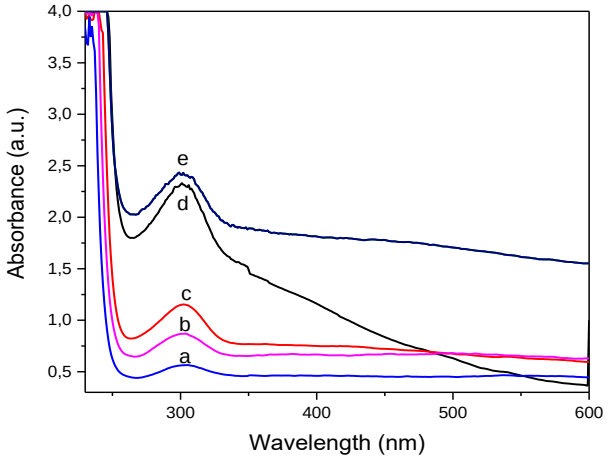


**Figure 3.** UV–Visible spectra of AgNP coating solutions at different $AgNO_3$/CMS concentrations (a.F025, b.F05, c. F1, d. F2, e.F5)

As a result of the UV-Vis analysis of the coating solutions containing silver nanoparticles, a distinct peak at 300 nm wavelength was observed. It was determined that the absorbance value of this peak increased due to the increase

in the amount of silver in the solution which reflects the formation of silver nanoparticles. All the solutions exhibited characteristic silver surface plasmon resonance (SPR) typically located in between 280-340 nm [1,20, 21, 22, 23].

Comparing with Fig. 3 a,b,c,d and e for the Ag nano-particles, a clear increase in the intensity of maximum absorption peak as well as a slight shift in the peak wavelength was noticed with increase of concentration. This study shows that the absorption intensity increases as the concentration of AgNP increases, which reflects in the formation of more Ag nanoparticles. The low wavelength and narrow peak width reflect a small particle size distribution [24] The narrower widths of the SPR bands confirm the smaller size and more uniform size distribution of the silver nano-particles by increasing concentration [4]. It seemed that the AgNPs absorbed radiation in the visible regions of 280–340 nm which agrees with the previous studies [21,24].

### 3.2. Electrical Conductivity and Surface Morphology

DC electrical conductivity measurements were performed by four point probe technique and calculated by Van der Pauw equation [25]:

$$\sigma\ (S/cm) = (In(2)i)\ /\ (\pi dV) \quad (1)$$

where d is coating thickness (cm), V is potential (Volt) and I is associated with current passing through the material (Ampere). The electrical conductivity measurements were repeated five times with different parts of the composite yarns and the arithmetic average of the results was used. The DC conductivity results of AgNPs coated PA composite yarns depending on $AgNO_3$/CMS concentration was given in Table 2.

**Table 2.** DC conductivity of AgNPs coated composite PA yarns depending on $AgNO_3$/CMS wt%

| Yarn Code | Thickness (µm) | Coating (%) | Conductivity (S/cm) |
|---|---|---|---|
| Uncoated | 590 | - | - |
| F025 | 597 | 0,7 | $1.015x10^{-5}$ |
| F05 | 601 | 1,1 | $3.782x10^{-4}$ |
| F1 | 602 | 1,2 | $1.347x10^{-2}$ |
| F2 | 605 | 1,5 | $6.541x10^{-2}$ |
| F5 | 609 | 1,9 | $1.282x10^{0}$ |

In the coating process of composite polyamide yarns; it was determined that the electrical conductivity increased from $1.015x10^{-5}$ S/cm to $1.282x10^{0}$ S/cm depending on the increase in $AgNO_3$/CMS concentration in the solutionA positive correlation was found between the coating thickness and electrical conductivity (Table 2). Associated with it, the classification of samples was carried out according to their resistivity (ohm/sq) as given in table 3 [26]. It has been determined that AgNPs coated PA composite yarns can be evaluated in the conductive class according to the DC electrical measurements.

**Table 3**. Surface Resıstıvıty Classıfıcatıon

| Classification | Surface resistivity (ohm/sq) |
|---|---|
| Conductive | $<10^5$ |
| Dissipative | $10^5$ to $10^{12}$ |
| Insulating | $>10^{12}$ |

The $AgNO_3$ concentration has a major role in fabrication of electrically conductive fibers. Carboxyl sites in polyamide chains cause the formation of a continuous silver nanoparticle network producing a nanolayer on the fiber surface with increasing of the concentration. In order to generate a conductive surface, homogeneous distribution of conductive silver particles without agglomeration is the key factor [13]. Therefore, scanning electron microscopy analysis was preferred to analyze the distribution of silver nanoparticles. Figure 4 shows the SEM images of uncoated PA yarn and silver coated PA yarns that were processed at different concentrations.

When the uncoated PA yarn has a smooth surface with the average diameter of 18.4 µm, the agglomerated formations are observed with the increasing of $AgNO_3$/CMS concentration. When the concentration increased, although the coating thickness increased, coating heterogeneity were observed especially for F2 ve F5-coded PA yarns. Similar results were obtained in the literature [10, 13, 27, 28,29]. However, homogeneously dispersed silver-coated thin layers were observed in the presence of F1-coded yarn (Figure 4). According to the electrical and morphological analysis, the concentration of $AgNO_3$/CMS was determined as [1:0,2] and F1-coded yarn was selected for the process time optimization studies in terms of both homogeneous distribution and sufficient conductivity level (Table 2, Figure 4).

The DC conductivity of F1-coded PA composite yarns depending on process time was given in Table 4.

In the coating process of composite PA yarns; it was determined that the electrical conductivity increased from $2.107x10^{-5}$ S/cm to $4.442x10^{-2}$ S/cm depending on the increase in process time. According to the Table 4, higher conductivity values were measured especially at the processing times of 3 hours and after. A positive correlation was found between the coating thickness and electrical conductivity with time (Table 4).

Figure 5 shows the SEM images of F1-coded yarns which were processed at different time.

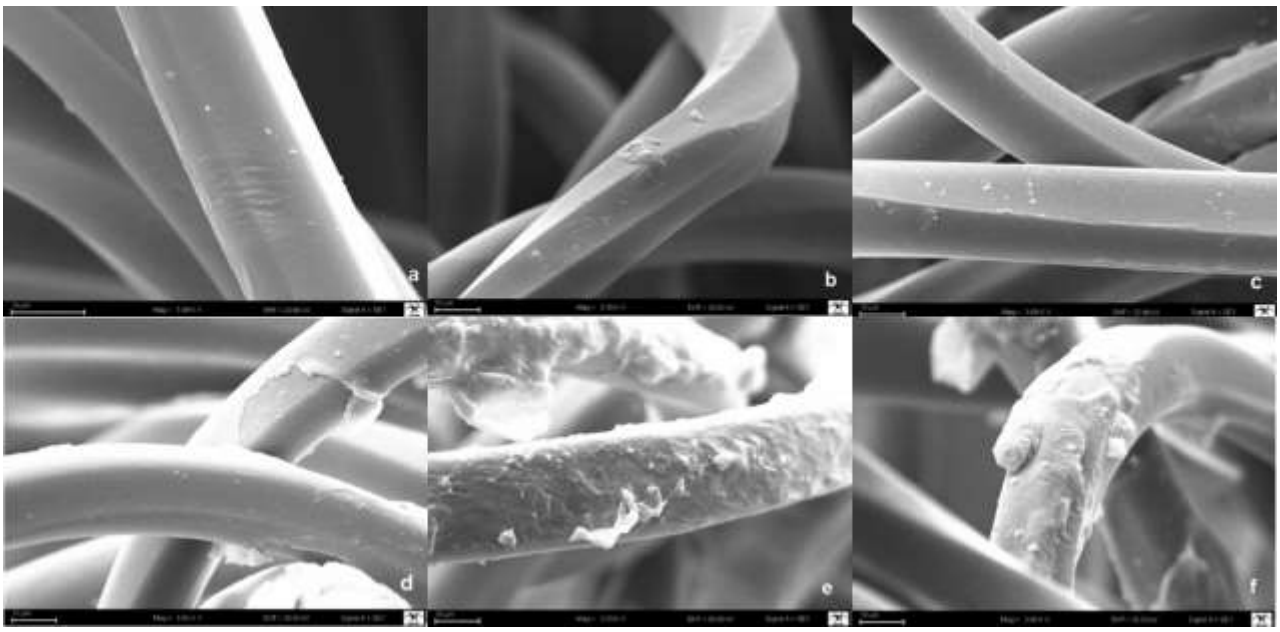

**Figure 4.** SEM images of AgNPs coated composite PA yarns (a. Uncoated yarn b. F025, c. F05, d. F1, e. F2, f. F5, Scale: 10 µm)

**Table 4.** DC conductivity of F1-coded composite PA yarns depending on process time

| Time (h) | Thickness (µm) | Coating (%) | Conductivity (S/cm) |
|---|---|---|---|
| Uncoated | 590 | - | - |
| 1 | 602 | 1,2 | $2{,}107 \times 10^{-5}$ |
| 2 | 604 | 1,4 | $3{,}754 \times 10^{-4}$ |
| 3 | 605 | 1,5 | $1{,}389 \times 10^{-2}$ |
| 4 | 606 | 1,6 | $4{,}250 \times 10^{-2}$ |
| 5 | 608 | 1,8 | $4{,}442 \times 10^{-2}$ |

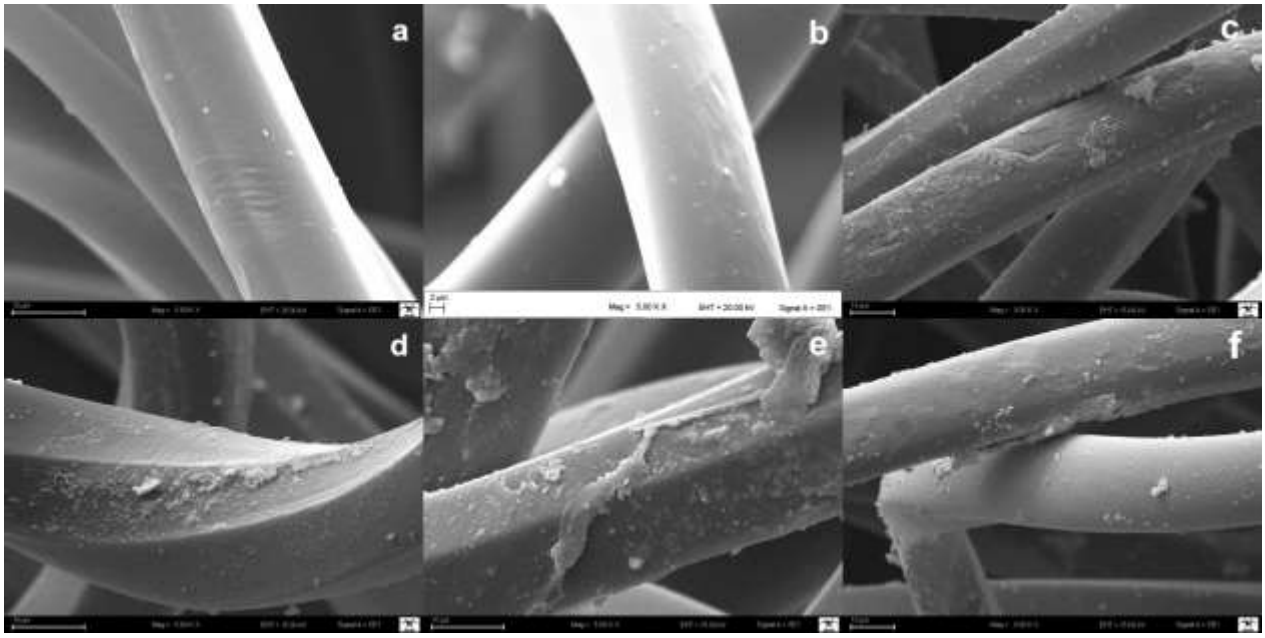

**Figure 5**. SEM images of AgNPs coated PA composite yarns (a.Uncoated yarn b. 1h, c. 2h, d. 3h, e. 4h f. 5h, Scale: 10 µm)

When F1-coded yarns were subjected to the coating process at different times, the presence of densely silver nanoparticles on the yarn surfaces werer observed with the increase of the processing time. Especially in the coating times between 3 and 5 hours, the presence of more dense and heteregeneous coating regions were observed. SEM images clearly depicted the formation of a nanolayer around the PA fibers and approved the importance of

process time on the surface morphology. According to the electrical conductivity and surface morphology analysis, optimum coating time was determined as 3 hours for F1-coded yarn (Figure 5).

The SEM-EDX results of F1-coded yarn is presented in Figure 6.

Spectrum: Acquisition

| Element | Series | unn. C [wt.%] | norm. C [wt.%] | Atom. C [at.%] | Error [wt.%] |
|---|---|---|---|---|---|
| Carbon | K-series | 1.52 | 37.23 | 55.80 | 0.3 |
| Oxygen | K-series | 1.44 | 35.19 | 39.59 | 0.3 |
| Silver | L-series | 1.13 | 27.57 | 4.60 | 0.1 |
| | Total: | 4.10 | 100.00 | 100.00 | |

**Figure 6.** SEM-EDX results of F1-coded yarn

Figure 6 presents the EDX spectrum of F1-coded yarn, and both weight percentages (wt %) and atomic percentages (at %) of the detected elements. Carbon and oxygen were detected in EDX spectrum due to the chemical structure of the polyamide yarns [13]. According to the EDX results of the F1-coded yarn, the percentage of silver atoms in the coated polyamide yarn was measured as 4.6% which shows a certain amount of silver nanoparticle coating on the PA yarn surface (Figure 6).

Polyamides are produced from a diamine and a dicarboxylic acid [30]. There is both electrostatic attraction and coordination interaction between Ag+ carboxylic and amine groups on the PA yarn surface. In the AgNPs process, the synthesized AgNPs can interact with the amine groups of the PA chains via electrostatic and coordination interaction [10]. Therefore, the AgNPs were finally attached on the PA chains. On the other hand, Ag NPs are formed on the surface by the reduction of CMS and immobilized by the coordination bonds between the hydroxyl groups of CMS and silver atoms on the surface of the Ag NPs [31,41]. The schematic presentation of the formation of silver NPs on the surface of PA yarns via reduction of Ag ions with CMS is shown in Figure 7.

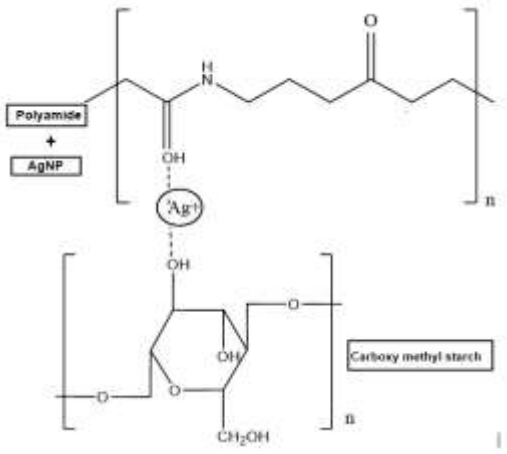


**Figure 7.** Schematic formation of AgNPs coated PA yarns

### 3.3. XRD Analysis

Basing on XRD analyses, the average size (DAg) of the Ag NPs in the modified cotton fabrics were calculated using the Debye–Scherrer equation:

$$D = K\lambda\ (\beta cos\Theta)^{-1} \quad (2)$$

where λ is the wavelength of the X-ray radiation (Cu Kα = 0.15418 nm), K is the constant, taken as 0.89, β is the line width at half-maximum height, and θ is the diffracting angle [6,31].

Figure 8 shows XRD pattern of uncoated PA yarn and F1-coded composite PA yarn.

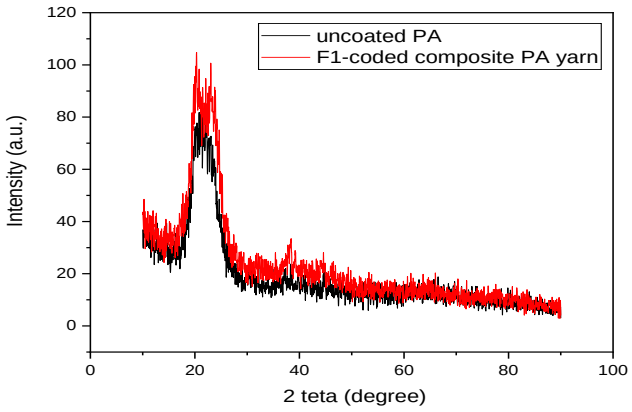


**Figure 8.** XRD patterns of uncoated and F1-coded composite PA yarn

It is observed that uncoated and coated PA yarns had two distinct diffraction peaks at 20.03° and 23.37° that related to nylon 6 crystals [3]. After AgNPs coating, it was observed that three different diffraction peaks appeared at 2θ values of about 38, 44 and 44 which could be assigned to the (111) and (200) diffractions of metallic silver, respectively (Figure 8). Additionaly, no characteristic peaks were observed for the other impurities such as $Ag_2O$ indicating synthesis of pure silver metal particles [13]. This leads to the high electrical conductivity of the fabric. Also, the sharp peaks suggest the formation of highly crystalline silver particles [6]. These results in compatible with literature which suggests silver nanoparticle crystals were successfully obtained [24, 31, 32, 33].

### 3.4. Antibacterial Properties

The antibacterial activity of AgNPs coated composite PA yarns are determined against Escherichia Coli (E Coli), Staph Aureus, Salmonella and Bacillus Cereus by disc diffusion or Kirby-Bauer method [14, 35, 36] according to (ISO 20645:2004) (Qualitative methods) [36-38].

According to this standard, a mixture of nutrient broth and nutrient agar in 1 L distilled water at pH 7.2 as well as the empty Petri plates were autoclaved. The agar medium was then cast into the Petri plates and cooled in laminar airflow.

Approximately $10^5$ colony-forming units of each bacterium were inoculated on plates [37,39].

The test specimen and pure control samples were cut into a disk shape with 6.5 mm diameter, sterilized by autoclaving for 20 min at 121◦C. The assessment of antibacterial activity was based on the observation of the presence of bacterial growth in the contact zone between agar and specimen (inhibition zone), on the appearance and size of the inhibition zone formed around the specimens and on the evaluation of bacterial growth under the sample [4,36].

Figure 9 and Table 5 present antibacterial activity of AgNPs coated composite PA yarns before and after washing in the presence of different $AgNO_3$/CMS concentrations.

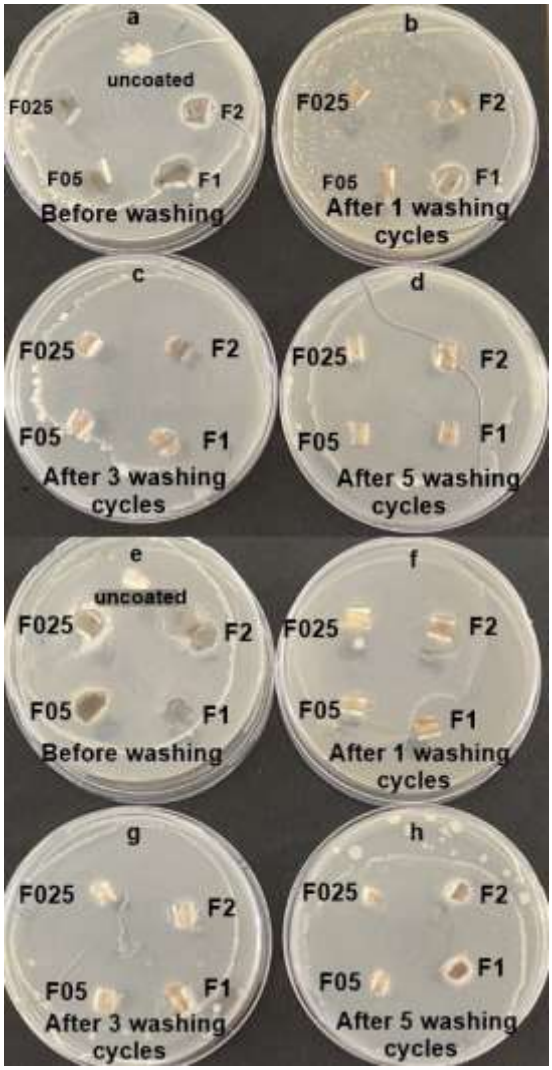


**Figure 9.** The antibacterial activity of AgNPs coated composite PA yarns and after different washing cycles in the presense of Escherichia Coli(a, b, c, d) and Staphaureus (e, f, g, h)

Figure 9 shows the zones of inhibition around AgNPs coated composite PA yarns after 24 h of incubation in dark at 37ºC. The test was repeated three times and the average value of inhibition zones are given in Table 5. Although antibacterial activity against all selected bacteria was good for all AgNPs coated composite PA yarns, inhibition zone measurements showed variation. The uncoated PA yarn showed no antibacterial activity. However, the zone of inhibitions was evidenced the antibacterial activity of selected bacteria such as Escherichia Coli and Staphaureus after coating process of PA yarn by $AgNO_3$. According to inhibition zone measurements, antibacterial activity increased with increasing $AgNO_3$/CMS concentration against all bacterial species. The highest inhibition zone values in two different bacterial species were obtained in F1 and F2 coded samples. The antibacterial property of coated yarns can be attributed to the combination of chemical and physical interactions of bacteria with silver particles. The results indicated that all tested yarns after 1, 3, and 5 washing cycles exhibited an antimicrobial activity (Table 5). The activity reduces gradually after washing with the increase in the washing cycle. These results are compatible wıth the literatüre [40].

### 3.5. Abrasion Resistance

Martindale abrasion tester determines the abrasion resistance of all kinds of textile structures with ISO 12945-2. Samples are rubbed against known abrasives at low pressures and in continuously changing directions. The amount of abrasion is compared against standard parameters [41].

F1 coded yarn with the highest electrical conductivity was selected for the abrasion resistance test. Table 6 shows the abrasion tester classification of F1 coded yarns.

The abrasion test results are given for AgNPs coated composite PA yarns in Table 6. After the abrasion test, bead formation was observed a little at 3000 cycles especially after coating. It has been determined that the abrasion resistance of the F1 coded yarn is not adversely affected after AgNPs coating.

## 4. CONCLUSION

In this study, an environmentally friendly green synthesis method without any organic chemicals was introduced to develop multifunctional AgNPs coated composite PA yarns with desirable electrically conductivity and antibacterial properties. The electrical conductivity increased depending on the increase of $AgNO_3$/CMS concentration. A positive correlation was found between the coating thickness and electrical conductivity. According to the electrical and morphological analysis, the concentration of $AgNO_3$/CMS was determined as [1:0,2] and F1-coded yarn was selected for the time optimization studies in terms of both homogeneous distribution and sufficient conductivity level. Antibacterial activity increased with increasing $AgNO_3$/CMS concentration against all bacterial species. The highest inhibition zone values in two different bacterial species were obtained in F1 and F2 coded samples. Our

study indicates that the in situ approach of silver nanoparticles to yarns shows a strong antimicrobial property and durability against washing even with low concentrations of $AgNO_3$. In summary, an environmentally friendly coating method has been developed that allows the formation of the silver nanoparticles on the PA yarn surface. The composite yarns can be used in a wide range of applications such as wound dressings, hygienic clothing and smart and technical textiles where the presence of bacteria is hazardous.

**Acknowledgement**

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**Table 5.** Inhibition zone of AgNPs coated composite PA yarns for different $AgNO_3$/CMS concentrations in the presense of E Coli and Staphaureus

| Yarn Code | Escherichia Coli | Staphaureus | Escherichia Coli | Staphaureus | Escherichia Coli | Staphaureus | Escherichia Coli | Staphaureus |
|---|---|---|---|---|---|---|---|---|
| | Inhibition Zone (mm) | | | | | | | |
| | **Before washing** | | **After 1 washing cycles** | | **After 3 washing cycles** | | **After 5 washing cycles** | |
| Uncoated | - | - | - | | - | | - | |
| F025 | 10,3 | 10,1 | 10,1 | 9,1 | 7 | 8 | - | 5,6 |
| F05 | 12,1 | 10,2 | 12 | 10 | 7,2 | 7,2 | 3,68 | 6,1 |
| F1 | 12,9 | 12 | 11,1 | 11 | 8 | 9,1 | 5 | 7 |
| F2 | 12,8 | 19,3 | 11,2 | 17 | 8,1 | 9,3 | 7,8 | 8 |

**Table 6.** The abrasion tester classification of F1 coded yarns

| **Test** | **Before the application** | | **After the application** | | **Test Method** |
|---|---|---|---|---|---|
| | Cycle | Classification | Cycle | Classification | |
| Determination of abrasion resistance of textile surface | 250 | 5 | 250 | 5 | TS EN ISO 12945-2 |
| | 500 | 5 | 500 | 5 | |
| | 1000 | 5 | 1000 | 5 | |
| | 1500 | 5 | 1500 | 5 | |
| | 2000 | 5 | 2000 | 4/5 | |
| | 2500 | 5 | 2500 | 4 | |
| | 3000 | 4 | 3000 | 3/4 | |

1 During friction the fibres constantly collide with each other and fibre fragments break due to fatigue damage, resulting in the breakage of the yarn.

2 The fibers are pulled out of the fabric, causing a loosening of the yarn/fabric structure. After repeated action the fibres may be pulled out, leading to thinning of the yarn and fabric, and even disintegration.

3 Fibers are cut and broken, leading to breakage of the yarn.

4 The fibre surface is worn and fragments are lost from the fibre surface.

5 Friction generates high temperatures, causing melt or plastic deformation of the fibers. Affects the structural and mechanical properties of the fibers.

## REFERENCES

1. Yu Z, Liu J, He H, Zhao Y W, Lu Q, Qin Y, Ke Y, Peng Y. 2021. Green Synthesis of Silver Nanoparticles with Black Rice (Oryza sativa L.) Extract Endowing Carboxymethyl Chitosan Modified Cotton with High Anti-microbial and Durable Properties, Cellulose 28, 1827–1842.
2. Sharma P, Pant S, Rai S. 2018. Green Synthesis and Characterization of Silver Nanoparticles by Allium cepa L. to Produce Silver Nano-coated Fabric and Their Antimicrobial Evalution, Applied Organometallic Chemistry 32, 4146.
3. Gawish S M, Ramadan A M, Sayed G H, Hussien A M. 2017. Synthesis, Characterization and Application of Silver nanoparticles for Synthetic Fabrics, International Journal of Pharmaceutical Sciences Review and Research 42(1), 307-311.
4. Ravindra S, Mohan Y M, Reddy N, Raju K.M. 2010. Fabrication of Antibacterial Cotton Fibres Loaded with Silver Nanoparticles via ‘’Green Approach’’, Colloids and surfaces A: Physicochemical and engineering aspects 367, 31-40.
5. Hebeish A A, El Rafie M H, Abdel-Mohdy F A, Abdel-Halim E S, Emam H E. 2010. Carboxymethyl Cellulose for Green Synthesis and Stabilization of Silver Nanoparticles, Carbohydrate polymers 82, 933-941.

6. Montazer M, Allahyarzadeh V. 2013. Electroless Plating of Silver Nanoparticles/Nanolayer on Polyester Fabric Using AgNO3/NaOH and Ammonia, Industrial & Engineering Chemistry Research 52, 8436−8444.
7. Gokarneshan N, Velumani K. 2017. Application of Nano Silver Particles on Textile Materials for Improvement of Antibacterial Finishes, Global Journal of Nanomedicine 2(3), 2573-2574.
8. Granados A, Pleixats R, Vallribera A. 2021. Recent Advances on Antimicrobial and Anti-Inflammatory Cotton Fabrics Containing Nanostructures, Molecules 26(10), 3008-3030.
9. Popa M, Pradell T, Crespo D, Calder´on-Moreno J M. 2007. Stable silver colloidal dispersions using short chain polyethylene glycol, Colloids and Surfaces A: Physicochemical and Engineering Aspects 303, 184–190.
10. Babaahmadi V, Montazer M. 2015. New Route to Synthesis Silver Nanoparticles on Polyamide Fabric Using Stannous Chloride, The Journal of The Textile Institute 106(9), 970-977.
11. Zhang X.F, Liu Z G, Shen W, Gurunathan S. 2016. Silver Nanoparticles: Synthesis, Characterization, Properties, Applications, and Therapeutic Approaches, International Journal of Molecular Sciences 17(9), 1534-1568.
12. Nadaroğlu H, Alayli Güngör A, İnce S. 2017. Synthesis of Nanoparticles by Green Synthesis Method. International Journal of Innovative Research and Reviews 1(1), 6-9.
13. Montazer M, Komeily Nia Z. 2015. Conductive Nylon Fabric Through In Situ Synthesis of Nano-silver: Preparation and characterization, Materials Science and Engineering:C 56, 341–347.
14. Hasan K M F, Pervez N, Talukder E, Sultana Z, Mahmud S, Meraz M, Bansal V, Genyang C. 2019. A Novel Coloration of Polyester Fabric through Green Silver Nanoparticles (G-AgNPs@PET), Applications of Magnetic Nanomaterials 9(4), 569-581.
15. Yoon S S, Lee K E, Cha H. 2015. Highly Conductive Graphene/Ag Hybrid Fibers for Flexible Fiber-Type Transistors, Scientific Reports 5,16366.
16. Dong C, Zhang X, Cai H, Cao C. 2014. Facile and One-step Synthesis of Monodisperse Silver Nanoparticles Using Gum Acacia in Aqueous Solution, Journal of Molecular Liquids 196, 135–141.
17. Ahmed H B, Emam H.E. 2016. Layer by Layer Assembly of Nanosilver for High Performance Cotton Fabrics, Fibers and Polymers 17(3), 418-426.
18. Hebeish A, El-Naggar M E, Fouda M G M. Ramadan M A. 2011. Highly Effective Antibacterial Textiles Containing Green Synthesized Silver Nanoparticles, Carbohydrate polymers 86, 936-940.
19. Dolaz M, Akarsu S. 2018. Synthesıs, characterızatıon and applıcatıon of carboxymethyl potato starch obtaıned from waste, Cellulose Chemıstry And Technology, 53 (1-2), 35-45.
20. Saad M A, Aldalbahia A, Al-hajjia A B, Chaudharyb A, Panhuis M, Ahamada T., Alhokbanya N. 2016. Development of carboxymethyl cellulose-based hydrogel andnanosilver composite as antimicrobial agents for UTI pathogens, Carbohydrate Polymers 138, 229–236.
21. Hebeish A, Hashem M, Abd El-Hady M M, Sharaf S. 2013. Development of CMC hydrogels loaded with silver nano-particles for medical applications, Carbohydrate Polymers 92, 407– 413.
22. Kanmani P, Lim S T. 2013. Synthesis and characterization of pullulan-mediated silver nanoparticles and its antimicrobial activities, Carbohydrate Polymers 97, 421– 428.
23. Ashayer-Soltani R, Hunt C, Thomas O. 2016. Fabrication of highly conductive stretchable textile with silver nanoparticles, Textile Research Journal 86(10), 1041–1049.
24. Montazer M, Alimohammadi F, Shamei A, Rahimi M K. 2012. In situ synthesis of nano silver on cotton using Tollens' reagent, Carbohydrate Polymers 87, 1706– 1712.
25. Van der Pauw, L. J. 1958. A Method of Measuring Specific Resistivity and Hall Effect of Discs of Arbitrary Shape. Philips Research Reports 12(1), 1-9.
26. İlkan Ö. 2020. Investigation of the technical and physical properties of metal composite 1×1 rib knitted fabrics, Industria Textila, 71(1), 41-49.
27. Alshehri S M, Aldalbahi A, Baker Al-hajji A, Chaudhary A A, Panhuis M, Alhokbany N, Ahamad T. 2016. Development of carboxymethyl cellulose-based hydrogel andnanosilver composite as antimicrobial agents for UTI pathogens, Carbohydrate Polymers 138, 229–236.
28. Xue C H, Chen J, Yin W, Tian Jia S, Zhong Ma J. 2012. Superhydrophobic conductive textiles with antibacterial property by coating fibers with silver nanoparticles. Applied Surface Science 258, 2468–2472.
29. Paola Rojas-Lema S, Gabriela Galeas-Hurtado S, Hugo Guerrero-Barragán V. 2017. Improvement of silver nanoparticle impregnation on cotton fabrics using a binder, Revista Facultad de Ingeniería (Rev. Fac. Ing.) 26(45), 109-119.
30. Montazer M, Shamei A, Almohammadi F. 2014. Synthesis of nanosilver on polyamide fabric using silver/ ammonia complex, Materials Science and Engineering: C 38, 170–176.
31. Xu Q, Ting Ke X, Shen L, Ge N, Zhang Y, Fu F, Liu X. 2018. Surface modification by carboxymethy chitosan via pad-dry-cure method for binding Ag NPs onto cotton fabric, International Journal of Biological Macromolecules 111, 796–803.
32. Moazzenchi B, Montazer M. 2019. Click electroless plating of nickel nanoparticles on polyester fabric: Electrical conductivity, magnetic and EMI shielding properties, Colloids and Surfaces A 571, 110–124.
33. Chauhan J, Mehto V R, Kumar D. 2019. Synthesis of Silver Nano Particles Using NaBH4 as Reducing Agent, International Journal of Applied Nanotechnology 5(1), 27-33.
34. Guzmán M, Dille J, Godet S. 2009. Synthesis of silver nanoparticles by chemical reduction method and their antibacterial activity, International Journal of Chemical and Biomolecular Engineering (2)3, 104-111.
35. Holubnycha V, Pogorielov M, Korniienko V. 2017. Antibacterial Activity of the New Copper Nanoparticles and Cu NPs/Chitosan Solution, IEEE 7th International Conference on Nanomaterials: Applications and Properties, Odessa, Ukraine.
36. Wu J, Zheng Y, Song W, Luan J, Wen Zhigu X, Chen X, Wang Q, Guo S. 2014. In situ synthesis of silver-nanoparticles/bacterial cellulose composites for slow-released antimicrobial wound dressing, Carbohydrate Polymers 102, 762-771.
37. Paszkiewicz M. Golabiewska A, Rajski A, Kowal E, Sajdak A, Zaleska-Medynska A. 2016. The Antibacterial and Antifungal Textile Properties Functionalized by Bimetallic Nanoparticles of Ag/Cu with Different Structures, Journal of Nanomaterials 2016, 1-13.
38. Shateri Khalil-Abad M, Yazdanshenas M.E. 2010. Superhydrophobic antibacterial cotton textiles, Journal of Colloid and Interface Science 351(1), 293-298.
39. Li W, Zhou L, Han Y, Zhu Y, Li Y. 2019. Effect of carboxymethyl starch on fine-grained hematite recovery by high-intensity magnetic separation: Experimental investigation and theoretical analysis, Powder Technology 343(1), 270-278.
40. Alshehri S M, Aldalbahi A, Al-hajji A B, Chaudhary A A. 2015. Development of carboxymethyl cellulose-based hydrogel andnanosilver composite as antimicrobial agents for UTI pathogens, Carbohydrate Polymers 138, 229–236.
41. Testex. 2022, 0606. Martindale Abrasion & Pilling Tester TF210. Retrieved from https://www.testextextile.com/product/martindale-abrasion-pilling-tester