Polymer Bulletin (2021) 78:4959–4975
https://doi.org/10.1007/s00289-020-03353-7

ORIGINAL PAPER

Preparation of antibacterial polyester–cotton absorbents; the effects of star-shaped functional oligomers

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Received: 7 March 2020 / Revised: 4 August 2020 / Accepted: 17 August 2020 /

Abstract

Antibacterial absorbent fabrics were prepared through by the immersion of polyester polyester–cotton fabrics in a soaking media, containing novel functional acrylic monomers and various antibacterial agents. 2-acrylamido 2-methyl propane sulfonic acid (AMPS) and a novel functional star-shaped oligomer (FSO) were used as monomers for inducing the absorbency and compatibility to the fabric. FSO in two steps and employing condensation reaction between glycerol and lactic acid via multi-step microwave irradiation was synthesized. Bio-based materials, such as gallic acid and tannic acid, were used as antibacterial agents to induce antibacterial activity to the cotton fabric. ATR-FTIR, H NMR, SEM, contact angle, as well as antibacterial activity, absorbency in distilled water and saline solution have been employed for further evaluation. The swelling capacity of the modified absorbent fabric H_1 (AMPS/FSO: 50:/50 wt%) was up to 21.1 g/g^{-1} in distilled water, and 6.1 g/g^{-1} in saline solution. Antibacterial properties tests of these absorbent fabrics showed a good antibacterial behavior, against *Staphylococcus aureus*.

Keywords Antibacterial · Absorbent · Swelling · Star-shaped oligomer · Gallic acid · Tannic acid · Polyester

Abbreviations

FSO	Functional star-shaped oligomers
AMPS	2-acrylamide-2-methyl propane sulfonic acid
APS	Ammonium persulfate
PEGDA	Polyethylene glycol diacrylate
TA	Tannic acid
GA	Gallic acid
LA	Lactic acid
AA	Acrylic acid
PTSA	P-toluene sulfonic acid

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Na OH	Sodium hydroxide
PET	Polyethylene terephthalate

Introduction

Nonwoven absorbent structures are versatilely used in hygienic products, such as napkins, wound dressings, medicine, and food [1]. Regarding the nonwoven absorbents, the extent of hydrophilicity is of great importance. In fact, poor absorption properties are a common problem associated with the nonwoven absorbents. Absorption capacity ultimately determines the volume of the fabric required to absorb a certain amount of physiological solutions, and so, it contributes the comfort of the user, during the wear [2]. Superabsorbent polymers (SAP) can be employed to enhance the absorbency of these products, but the direct dispersion of SAP powder particles over the fabric is not desired [2]. The most recognized problem, associated with the direct dispersion of SAPs in the fabric hygiene products, is the displacement of the particles of SAP powder. Therefore, the induction of absorbency—into the fiber or fabric, to achieve an inherently absorbent fabric, is an attractive research area.

Employing microgel latex, from inverse emulsion–polymerization, is a procedure for inducing uniform absorbency to a fiber or natural polymers, such as date seed [3] or starch [4]. In the first step, the microgel latex was synthesized through an inverse emulsion–polymerization of the hydrophilic acrylic monomers, such as acrylic acid, acrylamide, and 2-acrylamido 2-methyl propane sulfonic acid (AMPS). In the second step, the fiber or the natural polymer was immersed in the microgel latex for inducing absorbency. The resulted absorbencies were promising; however, possessing a two-step and often complicated processes, particularly in the preparation of the microgel latex are the main drawback of this method [3, 4].

The concept of ‘‘antibacterial finishing for textiles’’ was first stabilized in 1941, and since then, the textile industry has made a great progress in developing the antibacterial goods [5]. The growth of bacteria in textiles causes various hygiene problems and may result in human illness. In order to overcome the bacterial infections, different methods have been developed, i.e., embedding antibacterial agents into the fibers and fabrics [6]. In an attempt, the modification of the composite fibers surface was carried out, employing silver nanoparticles—through the radiation of gamma rays to improve the antibacterial performance of the fibers. However, the high cost of silver nanoparticles, as well as the change in the fibers color—after contacting with silver nanoparticles, limits the practicality of this method [7]. In another method, tannic acid was used without any stabilizer; through a one-step chemical synthesis method, tannic compartment was synthesized and deposited on cotton fabrics [8]. Moreover, studying the effect of various phenolic groups, such as gallic acid, on the linen fabrics, has shown that these compounds result in an increased antibacterial properties of the fabric [9]. Polyphenols, such as tannic acid or gallic acid, have aromatic rings with hydroxyl groups, which bestow anti-viral, antimicrobial, anti-oxidant, and anti-inflammatory properties to them [10].

The star-shaped polymers are one of the branching polymers. The star-shaped polymers often consisted of a hyper-branched core, and a number of linear arms. More often, the core has a hydrophilic nature and the arms are hydrophobic. This unique property provides spectacular features to the designed monomer. Nowadays, design and synthesis of monomers with star-shaped architectures have attracted many attentions, especially for thermosetting resins and composites [11]. In this context, the synthesis and characterization of a fistful of functionalized star-shaped lactic acid (LA)-based molecules, employing core molecules with different hydroxyl groups, and various arms, has been reported in the literature. For instance, the fabrication of a thermosetting resin, using LA (as arms) and xylitol (as the core molecule) in a two-step process has been reported by Jahandideh et al. The authors' results showed that the unsaturated branches of xylitol molecule may increase the hydrophilicity of the finished-resin, and in turn, it will make it more compatible with hydrophilic natural fibers [12]. The star-shaped oligomers are designed for various purposes, i.e., hydrogels, composites, thermosets, resins, adhesives, etc. [13–15].

Recently, the use of star-shaped oligomers in the synthesis of hydrogels has attracted many attentions. Regarding the hydrogels, the use of nonfunctional and functionalized star-shaped oligomers has been reported for various intentions. They have been employed as fillers, bio-based cross-linkers, for embedding novel properties in the hydrogels, or as a part of the backbone. Often, the synthesis of these star-shaped compartments was carried out by the condensation reaction of a core molecule, i.e., glycerin, with the chain-monomers, i.e., succinic acid (SA), lactic acid (LA), Sabzevari et al. [3], Dabbaghi et al. [16] and continues by a functionalization step, employing unsaturated compounds, i.e., methacrylic anhydride or itaconic acid (ITA) [3].

In this study, a novel bio-based functionalized star-shaped oligomer (FSO) based on glycerin, lactic acid, and acrylic acid was synthesized. A hydrophilic antibacterial fabric was prepared through the immersion of the polyester–cotton fabric, in a solution containing FSO and AMPS as monomers, and tannic acid and gallic acid as antibacterial agents. The effects of the commoner ratio as well as the antibacterial type and contents on the fabric properties were investigated. The hydrophilic antibacterial fabric has a potential to be used in hygienic applications, such as napkins, baby diapers, or absorbent pads for the meat packaging.

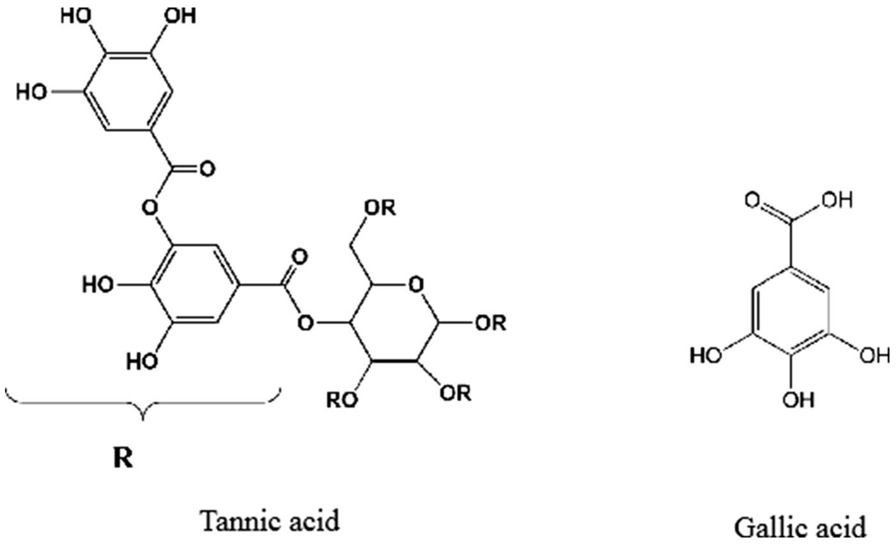
Experimental

Materials

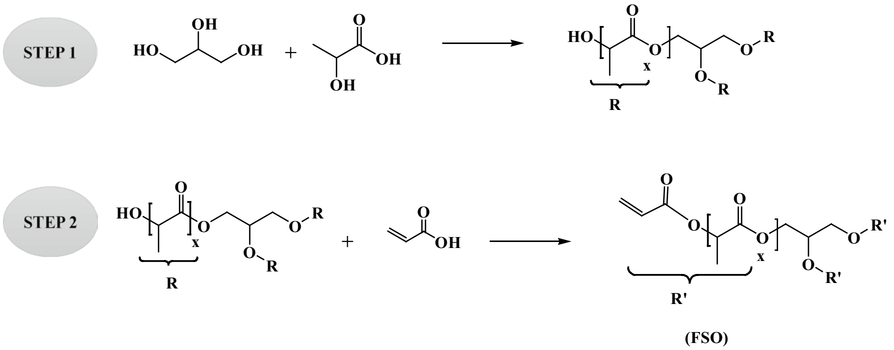
2-acrylamide-2-methyl propane sulfonic acid (AMPS, ≥98%; Purum) is used as a monomer for inducing hydrophilicity into the nonwoven fabrics. Glycerin (≥98%; Sigma) as a softener, ammonium persulfate (APS, ≥90%, Merck) as the initiator, and polyethylene glycol diacrylate (PEGDA, (PEGDA, Mw 400, Rahn, Switzerland,) as cross-linker were used in the modification of the nonwoven fabric. Tannic acid (TA, Merck KGaA, Darmstadt Germany) and gallic acid (GA, Merck KGaA, and Darmstadt Germany) were used as antibacterial agents during the fabric modification, and their structure is shown in Scheme 1. (L)-lactic acid (≥ 90%; LA, Merck), anhydrous glycerol (≥ 98%; Merck), and acrylic acid (LG, Korea) were used, during the synthesis of the acrylated star-shaped oligomers. P-toluene sulfonic acid (PTSA, ≥ 99.0%; Merck) was used as the catalyst for the poly condensation reactions. Sodium hydroxide (Na OH, ≥ 99.0%; Merck) and acetone (≥ 99.0%; Merck) was used treatment. The fabrics (50–50% of polyethylene terephthalate (PET) and cotton, 60 g m^{-2}, Bibaft Gostar Jahan, Iran) have been pre-treated by alkali solution, before the experiment.

Synthesis of the functionalized star-shaped oligomers (FSO)

The star-shaped oligomers were synthesized in two steps, employing condensation reaction between glycerol and lactic acid—via multi-step microwave irradiation, and following acrylation of these resins. Microwave irradiation leads to a fast temperature increase in the medium. In the first step, LA (6 mol) and glycerol (0.25 mol) were initially mixed and microwaved at 100 °C (1 min, 550 W); then, the catalyst (PTSA 0.1 wt%) was added. Temperature was maintained at ~ 120 °C, employing microwave irradiation (550 W, 3 min). Afterward, the remaining glycerol (0.25 mol) was added into the reactor. The reaction progress was ensured by monitoring the evaporation and measuring the removal of the condensation water. The microwave power was set to 250 W, to maintain the temperature between 120 and 130 °C, for 14 min. Finally, the reactants were kept at 140 °C for 14 min for a complete water removal. In the second step, in the absence of the inhibitor, the former resin was acrylated, by the addition of acrylic acid into the reactant medium through the microwave irradiation (12 min, 450 W) at ~ 120 °C (Scheme 2). The gelation was circumvented during the acrylation by maintaining the temperature in range of



Scheme 1 Structure of Tannic acid and gallic acid as antibacterial agents during the fabric modification



Scheme 2 Synthesis steps of functional star-shaped oligomers (FSO)

110–140 °C, by stirring the medium for 10 min periods, between the microwave irradiation intervals when necessary.

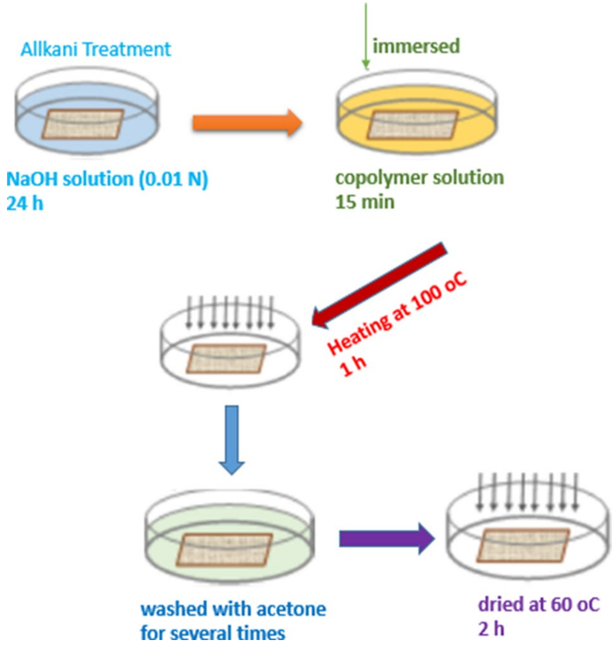
Fabric pretreatment and surface modification

Polyester–cotton fabrics were cut into 10×2.5 cm pieces and immersed for 24 h in a NaOH solution (0.01 N), to remove impurities. After that, the fabrics were washed and rinsed with distilled water several times and dried at 40 °C for 30 min (Scheme 3). Modification of the nonwoven fabrics was carried out to induce simultaneous hydrophilicity and antibacterial activity in the fabrics. The variable parameters in the fabric modification step were the ratio of AMPS to FSO, and antibacterial agent type and its content. Table 1 shows the composition of the modification media in each experiment. At room temperature, cotton–polyester fabrics were immersed in the modification solution, containing monomers, thermal initiator, cross-linking agent, and the antibacterial agent, for 15 min. Then, the impregnated fabric placed in an oven at 100 °C for 60 min. Afterward, the modified fabrics were washed with acetone, for several times, to remove the soluble fractions. The washed-modified fabrics were kept at 60 °C, for 120 min, to remove washing solvent (Scheme 3).

Characterization

Chemical characterization. Modified fabrics were evaluated by a spectrophotometer (Bruker Instrument, Vertex 80, and Germany). The ATR (Miracle, diamond, 45°) and ^{1}H NMR (Bruker 400 MHz, Germany) were used to study the structure of the modified fabrics. For ^{1}H NMR analysis, deuterated chloroform ($CDCl_3$) was used as solvent and chemical shifts (δ) were reported in parts per million (ppm).

Scanning electron microscopy. Scanning electron microscopy (SEM) (model VEGA3 TESCAN, Czech Republic) was used to study the fabrics microstructure. The fabrics surfaces were sputter coated with palladium–gold (30 nm Au layer) to evade charging.



Scheme 3 Schematic steps of antibacterial fabric preparation and modification presses by the obtained solution

Table 1 Composition of various samples used for modification of fabrics

Sample code	Monomer amps (wt%)	Monomer FSO (wt%)	Antibacterial agent (ANT)	ANT extent (g)
H_1	100	0	–	–
H_2	75	25	–	–
H_3	50	50	–	–
H_4	25	75	–	–
H_5	0	100	–	–
H_3AT_1	50	50	Tannic acid	0.2
H_3AT_2	50	50		0.4
H_3AG_1	50	50	Gallic acid	0.2
H_3AG_2	50	50		0.4
Non-modified	–	–	–	–

Swelling measurements

To measure the capacity of swelling, first, the modified fabrics were cut into 10×2.5 cm pieces and then, they were submerged in 100 mL water and 100 mL NaCl solution (0.9 wt%—Q_W and Q_S, respectively) for an hour at room temperature. The swelling capacity was calculated according to Eq. 1:

$$Q = \frac{W_s - W_d}{W_d} \qquad (1)$$

where Q (g g^{-1}) is the swelling capacity, and W_s (g g^{-1}) and W_d (g g^{-1}) are, respectively, the weight of dry and swollen fabrics, before and after swelling.

Static contact angle test (WAC)

The contact angle analysis was carried out to investigate the polarity and assess the hydrophilicity of the surface of the fabrics. In this method, a drop of water was placed on the surface of the test fabrics, and immediately, the photograph was taken from the contacting region of the droplet and the fabrics surface. The photograph was analyzed (ImageJ, model 1.42 q), and the contact angle was measured. For each sample, an average of three recording was reported.

Zone of inhibition test for antibacterial activity

Determination of antibacterial activity against *Staphylococcus aureus* (a gram-positive microorganism) and *E. Coli* (a gram-negative microorganism) was accomplished based on the agar diffusion and plate count methods [17]. The modified fabrics (12 numbers) were exposed to the bacteria, in a solid environment (nutrient agar), and the antibacterial properties were measured assessing the inhibition zone around fabrics. The fabrics were cut in circles (2 cm diameter) and placed in the agar plate, covered with 100 mL of bacterial suspension (108 CFU/mL), and incubated at 37 °C, for 24 h. Eventually, the diameters of the inhibition zone were evaluated to investigate the antibacterial properties of the fabrics. For this purpose, software ImageJ was used that measures the size zone of inhibition based on the ratio of the area of the antibacterial to the total area of the fabric.

Results and discussion

FTIR-ATR analysis

Figure 1 represents the ATR-FTIR spectra of various modified fabrics, including alkali-modified, FSO-modified, AMPS-modified, and (FSO–AMPS)-modified fabrics. From Fig. 1a, the characteristic absorption peaks of non-modified sample were observed at 1714, 1240, and 1095 cm^{-1}, attributed to C=O stretching, C–O, and C–O–C symmetric, respectively [18]. Figure 1b shows absorption peaks at 1722, 1244, 1093, 1053, and 1029 cm^{-1} which were assigned to the symmetric C=O stretching, C–O (connected to the benzene ring), C–O–C symmetric, and C–O–C aliphatic. The signal attributed to C=C (at 1634 cm^{-1}, in Fig. 1b) has been disappeared, owing to the occurrence of the radical polymerization during the modification. The peaks at 2914, 3336, and 3280 cm^{-1} were assigned to CH_3 of LA and hydroxyl groups of FSO (Fig. 1b) [18–20].

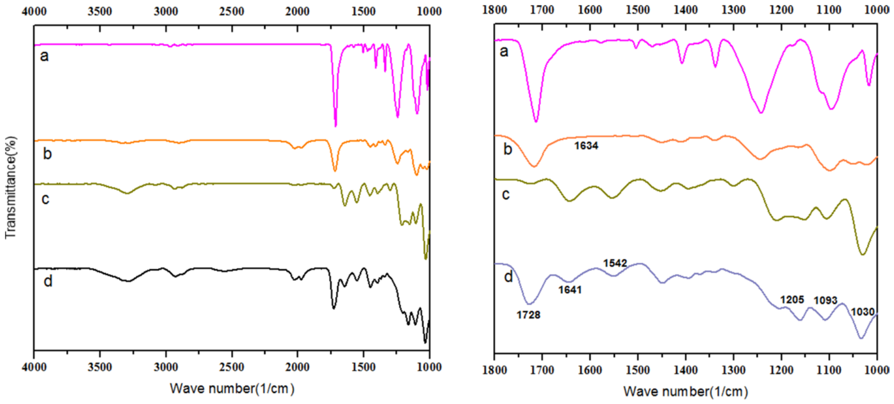


Fig. 1 ATR-FTIR spectra of **a** non-modified, **b** H_5, **c** H_1, and (d) H_3

In Fig. 1, characteristic absorption peaks of the H_1 fabrics are visible: ether symmetric at 1095 cm^{-1}, ether aliphatic at 1030 cm^{-1}, C–N at 1207 cm^{-1}, S=O stretching symmetric at 1145 cm^{-1}, S=O–OH at 1737 cm^{-1}, C=O–NH_2 at 1645 cm^{-1}, NH bending at 1546 cm^{-1}, N–H stretching at 3307 cm^{-1}, and =C–H at 3087 cm^{-1} [21]. Figure 1d presents the spectrum related to the modified fibers with (FSO–CO–AMPS), the peak at 1093 cm^{-1} area confirmed the presence of COOH groups, and peaks at 1031, 1163, and 1205 cm^{-1} could be assigned to the symmetric C–O–C aliphatic, S=O, and C–N, respectively. The band observed at 2925 cm^{-1} has been attributed to the CH_3 LA, and the peaks at 1728, 1641, and 1542 cm^{-1} could be assigned to symmetric OH–S=O, C=O–NH_2, and NH bending, respectively. In addition, two peaks at 3300 and 3074 cm^{-1} have been attributed to NH stretching and =C–H, respectively.

^{1}H-NMR analysis

The ^{1}H-NMR spectra of the synthesized monomer are represented in Fig. 2. The peaks were assigned based on the literature or the authors' previous reports on the star-shaped architectures. The chemical structure of resins has been discussed in authors' previous work in details. The peaks revealed at ~ 1.5 ppm, denoted by e in Fig. 2, have been attributed to the CH3 groups of lactic acid in the chains [22]. As the lengths of the chains would not be identical, multiple peaks have been observed in this range, which is in accordance with the results reported in the former reports.

The peak at 4.34 ppm (Fig. 2f) shows lactic acid group in the star-shaped oligomer structure [23]. The acrylic acid hydrogens marked with the letters h, i, and g in Fig. 2, in the spectrum, were seen at 5.98, 6.15, and 6.44 ppm, respectively. Also, the CH and CH_2 groups of glycerol were reported in the range of 3.6–3.8 ppm (Fig. 2k, j). The multiple natures of these peaks clearly denote that both terminal LA units, as well as the glycerol hydroxyl groups have been reacted with acrylic acid. No peak observed at ~ 12 ppm, which confirms that there is almost no unreacted acrylic acid presented in the resin. The absence of peaks at ~ 11 ppm also indicates

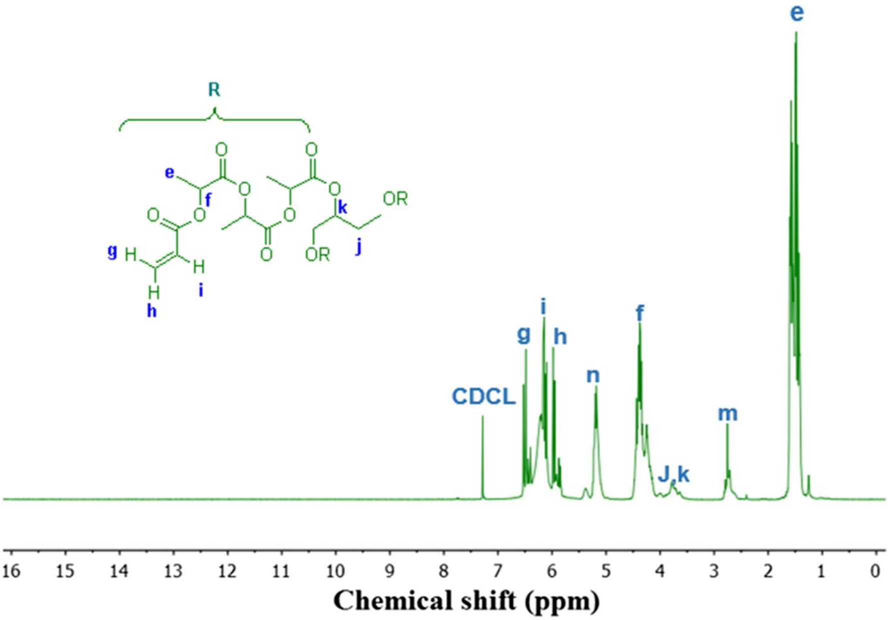


Fig. 2 ^{1}H NMR spectra for the functional star-shaped oligomer

that no unreacted LA is available at the end of the chains [23]. Furthermore, the peaks at 2.89 ppm (Fig. 2m) and 5.10 ppm (Fig. 2n) were attributed to the CH_3 and CH groups of LA, respectively, which was confirmed by ^{1}H-NMR spectra as well [11] (see Fig. 2).

Swelling studies

Effect of monomers content on the swelling capacity

Table 2 tabulates the swelling capacities of modified nonwoven fabrics, based on the composition in the immersion media. The modification condition for all fabrics was identical (at 100 °C, for 1 h, see Scheme 3). During the heating period, the thermal decomposition of APS initiator was occurred, and subsequently, cross-linking polymerization was carried out on the nonwoven fabrics. The results indicated that the modification of nonwoven fabrics was successful. In fact, the modification-induced hydrophilicity into fabrics: the swelling capacity of the polyester–cotton fabric (non-modified) in distilled water and saline was 10.3 and 1.41 g g^{-1} before the modification. It has been increased to 36 and 6 g g^{-1}, after the fabric modification (H_1). Increasing the AMPS contribution in the modification media enhanced the swelling capacity of the modified fabric; the swelling capacity of H_1 sample was 36.01 and 6.75 g g^{-1}.

The rate of swelling in the network is determined by four forces or factors:

Table 2 Swelling capacity of fabrics, modified by different monomers used in this study

Sample code	Q_{dw} (g g^{-1})	Q_{s} (g g^{-1})
H1	36	6.8
H2	31.5	5.8
H3	21.1	6.1
H4	10.3	3.8
H5	1.7	2.3
H3AT1	14.6	6.8
H3AT2	14.9	6
H3AG1	12.6	5.4
H3AG2	10	5.7
Non-modified	10.3	1.4

1. Polymer–solvent interaction.
2. Elastic interaction.
3. Electrostatic repulsion of homogeneous ions.
4. Mobility of ionic groups attached to polymer chains.

That Factor 3, especially 4, is the significant effect on the swelling in ionic environments, which reduces the osmotic pressure difference inside and outside the polymer network.

Therefore, the high sensitivity of ionic solutions (water saline) causes a sharp decrease in their rate of swelling in ionic environments.

This trend can be explained based on the differences in the nature of AMPS and FSO. In fact, AMPS is an ionic monomer with a sulfonic acid group in its structure. Sulfonic acid has a high tendency for dissociation and creates mobile ions [14–16], which cause osmotic pressure gradient between the gel and the solvent phase. Neutralization is not necessary to induce dissociation ability when strong sulfonic acid is used. [14–16]. The star-shaped oligomers performance as large groups prevents the formation of hydrogen bonds in the modified solution structure. Moreover, with the increase in FSO monomers, the possibility entanglement of the chain increases and it causes the agglomeration phenomenon that both of these factors reduce the amount of swelling by absorbent fabrics. In fact, FSO has a nonionic nature with negligible hydrophilicity and has been used to increase the biocompatibility.

The effect of antibacterial agent content

For inducing antibacterial activity to non-modified fabric, tannic acid and gallic acid were added directly to the modification media (H_3., Scheme 3). Table 2 shows the swelling capacity of the modified fabrics employing different antibacterial agents. The results show that by adding antibacterial compounds into the modification media, the water adsorption capacity of the modified fabric has significantly decreased. The swelling capacity of the H_3 sample was initially 21.1 g g^{-1} in distilled water; it was decreased to 14.5 and 12.6 g g^{-1}, by adding 0.2 g tannic acid (H_3AT_1) and gallic acid (H_3AG_1) into the modification media, respectively (see Table 2). This can be attributed to the chemical structure of these antibacterial agents. It is concluded that the phenolic groups in tannic acid and gallic acid would have interactions (i.e., hydrogen bonding) with the AMPS and FSO. These additional interactions can act as cross-linker and increase the cross-linking density, which in turn results in a swelling capacity reduction. Cross-linking can be occurred through two ways: first, the presence of multifunctional acrylic monomer (i.e., PEGDA 400) in the cross-linking polymerization results in cross-linking, and second, the presence of phenolic groups in the modification media, which forms hydrogen bonding between the polymer structure and the antibacterial agent promotes the cross-linking. Therefore, cross-linking is increased in the presence of antibacterial agents and consequently yields swelling capacity reduction.

Wettability analysis

Figure 3 shows the contact angle analysis and wettability behavior of the pristine, absorbent fabrics, and the absorbent antibacterial modified fabrics. According to the figure, the water contact angles for non-modified, H_3, H_3AT_1, and H_3AG_1 fabrics were 119.5°, 78.1°, 75.3°, and 68.0°, respectively. As shown in Fig. 3, the pristine fabric shows a hydrophobic nature, whereas the modified fabrics have shown hydrophilic behavior ($H_3AT_1 > H_3AG_1 > H_3$). Comparison of the wettability behaviors of the pristine fabric with the modified fabrics shows that the presence of hydrophilic groups in the structure of FSO and AMPS monomers increases the hydrophilicity of the modified fabrics. In Fig. 3, it is observed that the addition of tannic acid and gallic acid does not have a negative effect on the hydrophilic properties of the absorbent fabric.

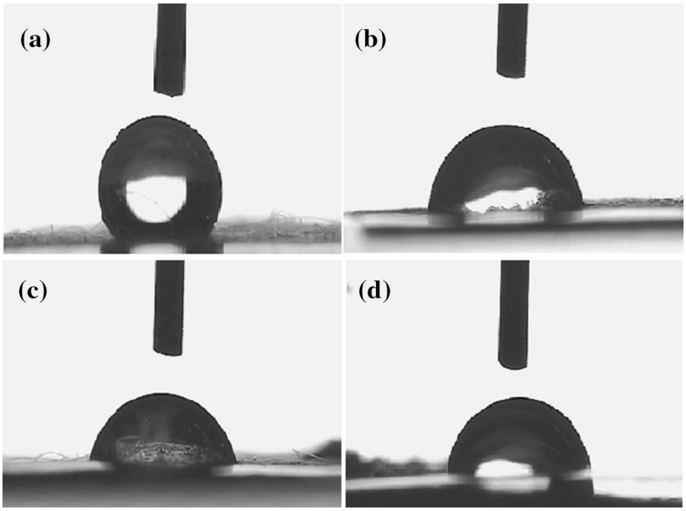


Fig. 3 Digital images of water droplets on the fabrics surface. **a** Non-modified, **b** H_3, **c** H_3AT_1, **d** H_3AG_1

Morphology of the fabrics

Figure 4 shows images of the scanning electron microscope (SEM) for the pristine, absorbent fabric, and the antibacterial absorbent fabric. Comparison of the pristine fabrics and b samples shows that the modification of the surface of the nonwoven fabrics has been identical and successful. The surface of the nonwoven fabric is completely covered with AMPS and FSO (H_3) after the modification. During the modification, the chemical reaction between the hydroxyl groups of the nonwoven fabric and the carboxylic acid groups of FSO has been occurred; consequently, the surface of nonwoven fabrics is covered with hydrophilic groups which induced the absorbency to the fabric. Uniform covering of the nonwoven fabric is also achieved in case of antibacterial absorbent fabrics (Fig. 4c, d). Images show that tannic acid and gallic acid have no adverse effect on the uniform covering of the nonwoven fabrics with hydrophilic monomers.

Antibacterial activity tests

Figure 5 represents antibacterial activities of absorbent fabrics against *S. aureus* and *Escherichia coli*, using the inhibition zone test. The antimicrobial agents, i.e., tannic acid or gallic acid, were used for inducing antibacterial activity into the nonwoven fabrics. Phenolic acids from this group are natural substances that are found in many

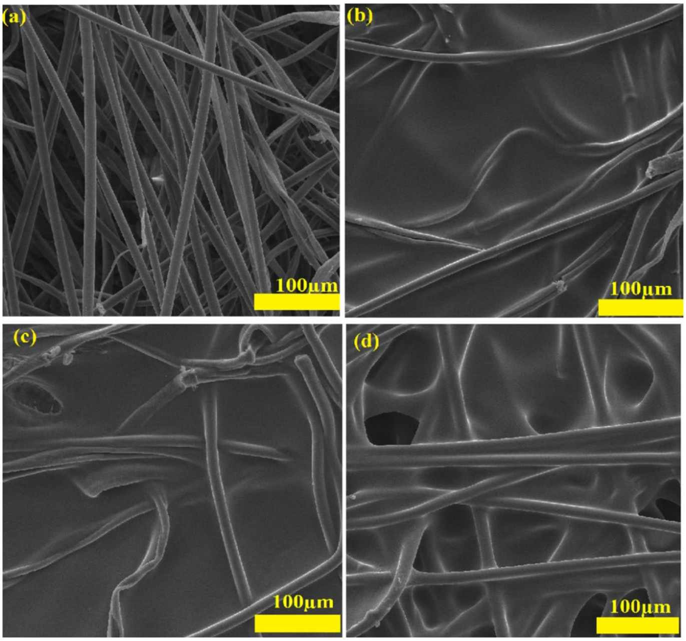


Fig. 4 SEM images of various antibacterial absorbent sheets at magnification of 100micron (fibrils). **a** Non-modified, **b** H_3, **c** H_3AT_1, **d** H_3AG_1

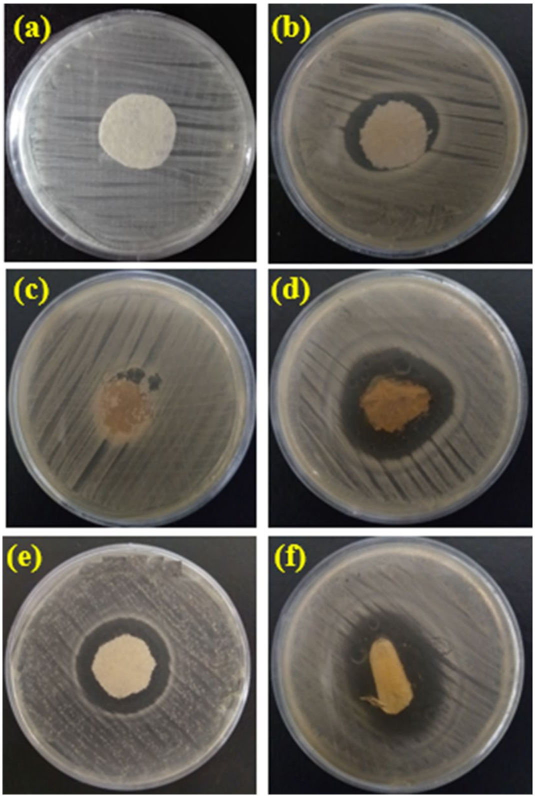


Fig. 5 The investigation of the antibacterial activities against *S. aureus*, employing the inhibition zone test for **a** non-modified, **b** H_3, **c** and **d** H_3AT_1 and H_3AT_2, **e** and **f** H_3AG_1 and H_3AG_2

plants as natural antioxidants which can inhibit pathogen growth and have less toxicity than host cells. For this reason, they can be used to create antimicrobial properties on textiles. The antibacterial agents were used at two levels. All fabrics have shown antibacterial activities, while no antibacterial activity has been reported for the pristine fabrics. The inhibition area was found to be a function of the antibacterial agent type and its contribution in the immersion medium. Table 3 presents the normalized zone of inhibition areas for various samples, based on the ratio of the area of inhibition zone, to area of the analyzed fabric.

In Fig. 5, the b sample has shown antibacterial behavior; this observation has been attributed to the presence of sulfonic acid ions in the AMPS monomer which is one of the ions with antibacterial properties. According to Table 3 and Fig. 6, the areas of inhibition zones for the tested samples are in the following order:

$$H_3AG_2 > H_3AT_2 > H_3AG_1 > H_3AT_1$$

These results show that both gallic acid and tannic acid can successfully induce antibacterial activity into nonwoven fabrics. The phenolic groups in the structure of tannic acid or gallic acid have a natural antimicrobial property. Also, the ion

Table 3 Ratios of the inhibited zone of each sample to the area of each modified and unmodified sheets for various samples

Sample (sheet)	*S. aureus*			*E. Coli*		
	Area of sheet (a (cm^2))	Area of inhibition zone (b (cm^2))	Ratio of inhibition zone area to sheet area (b/a)	Area of sheet (a (cm^2))	Area of inhibition zone (b (cm^2))	Ratio of inhibition zone area to sheet area (b/a)
Non-modified	3.35	0	0	3.18	0	0
H3	6.44	4.06	0.63	3.07	0.76	0.24
H3AT1	2.62	1.34	0.51	3.37	0	0
H3AT2	2.70	5	1.85	2.30	0.19	0.08
H3AG1	4.76	6.63	1.39	1.27	2.63	2.07
H3AG2	3	10.39	3.46	1.66	4.11	2.47

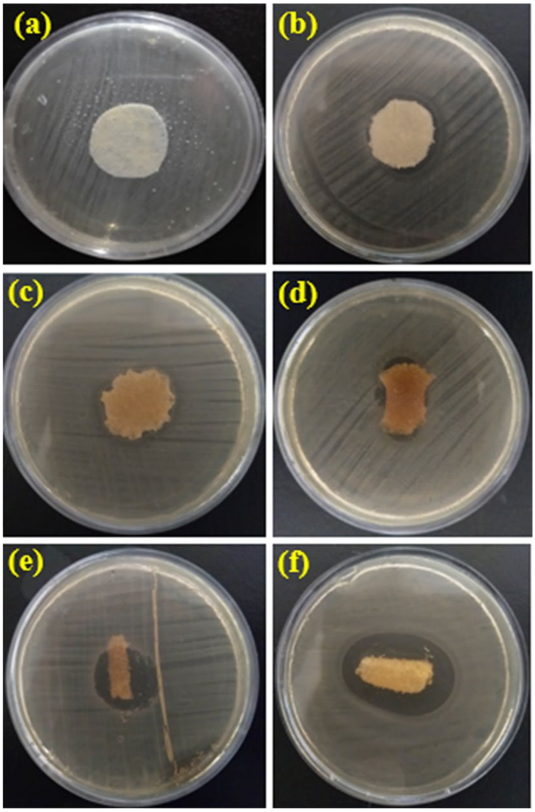


Fig. 6 The investigation of the antibacterial activities against *E. Coli*, employing the inhibition zone test for **a** non-modified, **b** H_3, **c** and **d** H_3AT_1 and H_3AT_2, **e** and **f** H_3AG_1 and H_3AG_2

exchange reaction with 2 Acrylamide 2 methyl propane sulfonic acid sodium salt as stronger anion can more practicably attract the phenolic groups. Kyung Hwa Hong used the gallic acid with 4-HBA, which gallic acid showed more antibacterial properties [9, 24].

Conclusions

A functional star oligomer (FSO) was designed and synthesized for inducing biocompatibility to the polyester–cotton fabrics. Modification media was formulated for inducing both hydrophilicity and antibacterial activity to nonwoven fabrics. Hydrophilicity induced by the employment of AMPS hydrophilic monomers and the FSO monomer, and the antibacterial activity resulted from utilization of gallic acid and tannic acid. SEM images showed that the nonwoven fibers have been uniformly covered by the modification medium, containing AMPS, FSO, and the antibacterial agent. The swelling capacity of the modified fabric (H_3) was up to 21.6 g g^{-1} in distilled water, comparably higher than that of the pristine one. Antibacterial activity tests showed that both fabrics, treated either by tannic acid or gallic acid, have antibacterial properties. Compared with tannic acid treated samples, gallic acid-treated fabrics presented higher antibacterial activity. Antibacterial absorbent fabrics are desired materials to be used in various applications, i.e., for medical, food or in hygiene products, such as napkins and wound dressings, meat and protein packaging, surgery dress, military clothing.

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