Received: 16 July 2023 | Revised: 29 September 2023 | Accepted: 5 October 2023
DOI: 10.1002/app.54837

RESEARCH ARTICLE

Journal of Applied Polymer Science WILEY

Investigation of water absorption performance of polyester-woven fabrics coated with super absorbent polymer

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Funding information
TUBITAK-The Scientific and Technological Research Council of Türkiye, Grant/Award Number: 5220066

Abstract

Superabsorbent polymers (SAPs) constitute a special class of polymers widely used in various fields, especially in the hygiene and healthcare sectors. This study investigates the feasibility of achieving high water absorption capacity surfaces by coating powdered SAP using conventional coating methods onto textile surfaces. For this purpose, water-based coating pastes containing micronized SAP powder based on acrylamide/acrylic acid copolymer were coated onto polyester (PES)-woven fabric surfaces using a knife-over-roll coating technique. As the working parameters, the pH value of the coating paste, the coating thickness (the distance between the cloth and the knife), the drying/fixing temperature and time, the SAP concentration, and the water absorption capacity according to time were investigated. The results were evaluated by applying the coating thickness, the amount of coating material transferred to the fabric on the SAP-coated samples, water absorbing capacity, and centrifugal water retention tests. The obtained results have demonstrated that textile surfaces with high water absorption capacity (on average 200%–350%) can be achieved by coating hydrophobic fabric surfaces, such as PES, with SAP under suitable conditions.

KEYWORDS

hydrophilic surface modification, PES-woven fabric, super absorbent polymer (SAP), textile coating, water absorption capacity

1 | INTRODUCTION

Superabsorbent polymers (SAPs) are a class of polymers that can absorb water at much higher rates (over 100 times their weight) compared with traditional absorbent materials.[1] In practice, sodium and potassium polyacrylate-based SAPs prepared by polymerizing acrylic acid with a crosslinking agent are well known.[2] SAPs are widely used in various fields where high levels of water/liquid absorption are required, and swollen gels are desired to release the absorbed water slowly and in a controlled manner through evaporation into the surrounding environment. SAPs have a wide range of applications due to their high water absorption capacity, biodegradability, and low cost.[3]

J Appl Polym Sci. 2024;141:e54837.
https://doi.org/10.1002/app.54837

Agriculture, construction, hygiene, food, health, medicine, and personal care sectors are the main using areas.[4] The extensive use of SAPs in both hygienic and nonhygienic applications has made them highly popular, leading to significant research interest in this field.[5]

Sodium polyacrylate chains with hydrophilic carboxylic groups (—COONa, etc.) that form the structure of SAPs intertwine with each other and form a low-density cross-linked polymer network (Figure 1). SAPs have excellent water absorption and water retention performance resulting from the slightly cross-linked three-dimensional network structure and the presence of many hydrophilic functional groups such as hydroxyl and carboxyl groups.[6,7] When SAP interacts with water, a large number of Na^+ ions will dissociate from the sodium carboxylate groups, increasing the osmotic pressure in the polymer network and leaving a large number of negative charges in the chains. Because of the repulsion between the negatively charged chains, the polymer network expands, and a large amount of water molecules are adsorbed in the polymer network under the effect of osmotic pressure.[8] The swelling capacity of SAPs depends on the structure of the monomer, the amount and type of cross-linker, the crosslinking density, that is, the synthesis parameters, and the ion concentration in aqueous solutions.[9,10]

In most traditional absorbent products, the powder form of SAPs is used in multilayered structures. Such products have disadvantages, such as displacement and slippage during the manufacturing process, handling, and/or use, due to the inability of the SAPs to be sufficiently immobilized within the product. Because of this displacement of the polymer particles, nonuniform absorbency problems arise. While it causes insufficient liquid storage in one part of the product, it causes excessive aggregation in other regions. This situation limits the use of powdered SAP in different areas.[12]

Today, global trends in the textile industry focus on developing and producing functional textile products with high-added value. The global market for high-performance textiles is growing at an unprecedented rate. The market size for high-performance textiles is estimated to exceed approximately $251.82 billion by 2027.[13] Polymer-coated textiles in this field are flexible composite materials consisting of the textile and the polymer layers bonded with specialized coating methods to provide additional features for textile surfaces.[14] While protecting the appearance and comfort of fabrics with nano- and microparticle coatings onto textile surfaces used as the base, potential application opportunities are offered by providing ultraviolet protection, antimicrobial properties, flame retardancy, water repellency, and self-cleaning properties.[15]

In recent years, numerous studies have been conducted on SAPs, and different research works are ongoing in this field. The four main polymerization methods for preparing SAPs, including bulk polymerization, solution polymerization, suspension polymerization, and radiation polymerization, have been described along with their advantages and disadvantages. The advantage of bulk polymerization is its ability to produce high-molecular-weight polymers with high purity without the need for complex equipment. In comparison to bulk polymerization, solution polymerization makes it easier to control the temperature and molecular weight of the product.[16] Apart from the polyurethane-based coating studies with a coating paste containing powdered SAP,[17,18] no academic study has been found in the literature on water-based coating applications.

This study aims to obtain textile structures with high water absorption capacity by coating hydrophobic textile surfaces such as polyester (PES) with the powder form of SAPs and, at the same time, to reveal new usage areas for SAPs. The performance of the coated fabrics was evaluated by analyzing gravimetric measurements, abrasion resistance, water absorption capacity, and centrifuge water retention capacity.

2 | EXPERIMENTAL

2.1 | Materials

In this study, the use of PES-woven fabric, a hydrophobic fiber, was preferred to eliminate the hydrophilic effect that may come from the fabric. The woven fabric used in the study was supplied by Kirayteks Inc. (Bursa, Turkey), and its technical properties are given in Table 1.

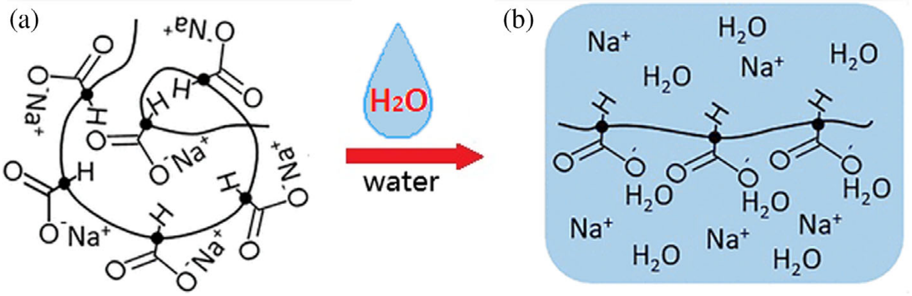


FIGURE 1 Schematic showing the interaction of poly(acrylic acid)-based superabsorbent polymers (SAPs) with water. (a) Dry SAP. (b) Swollen SAP after interaction with water.[11] [Color figure can be viewed at wileyonlinelibrary.com]

Micronized powder SAP, the main component of the experimental study, was supplied by Evonik Industries (Germany). Technical specifications of SAP are given in Table 2.

The binder, cross-linker agent, anti-foam agent, and dye used in the coating paste were sourced from Rudolf-Duraner and Duraner Inc. (Bursa, Turkey) companies, and their specifications are provided in Table 3.

2.2 | Method

2.2.1 | Coating process

The preparation of the coating pastes was carried out using an ATAC ATC-MX01 (Turkey) laboratory-type mixer. Initially, water and antifoam agents were mixed according to the application recipe provided in Table 4. Then, the micronized SAP powder was gradually added to the mixing solution while stirring. The mixing process was conducted for 20 min at a speed of 2000 rpm.

The viscosity measurements of the prepared coating paste were performed using the SOIF NDJ-8S Digital Viscometer at 60 rpm with the number 4 spindle. The viscosity of the coating paste was maintained within the range of 8500–9000 cP.

The pH of the coating paste was measured using the Milwaukee MW102 PRO Portable Digital pH Meter.

Coating and drying were carried out in the ATAC GK40 RKL laboratory-type automatic coating machine according to the knife-over-roll coating technique. Since the amount of coating paste transferred to the fabric can be adjusted more precisely, the knife-over-roll method was preferred instead of the knife-on-air.

For the drying temperature optimization of the SAP-coated fabrics, the drying processes were conducted at four different temperatures (130, 140, 150, and 160°C) using the coating process conditions provided in Table 5. The adequacy of the drying temperatures was determined by measuring the abrasion resistance at 2000 cycles using the Martindale abrasion and pilling tester device.

In addition, studies were conducted to optimize the drying time of the coated fabrics based on the coating thickness, using the coating process conditions provided in Table 6. These studies were carried out with four different coating thicknesses (0.25, 0.50, 0.75, and 1.00 mm)

TABLE 1 Technical properties of the woven fabric used in the coating.

Fiber type	100% PES
Woven structure/ weave type	Plain weave
Warp yarn count	300 D/72 f Textured Soft IMG S. Matte
Weft yarn count	300 D/72 f Textured S. Matte 100% PES Ecru
Warp density (warp/cm)	20
Weft density (weft/cm)	18
Mass per unit area (g/m^2)	152
Preparation process	Continuous washing/drying at 110°C

Abbreviation: PES, polyester.

TABLE 2 Technical properties of micronized powder super absorbent polymer.

Chemical basis	Cross-linked acrylamide/ acrylic acid copolymer
Physical form	Granular powder
Color	White
Median particle size range	0–90 μ (>90 μ maximum 2%)
Minimum absorption capacity (deionized water)	>150 g/g
Minimum absorption against pressure (0.3 psi load; 2-h value) (deionized water)	>10 g/g
Apparent bulk density	500–700 g/L
Moisture content	5 ± 2%

TABLE 3 Technical properties of coating chemicals.

Chemical	Property
Crosslinking agent	Blocked isocyanate cross-linker agent, *N*-methylene-2-pyrrolidone, and butanone-oxime-free, anionic
Antifoam	Preparation of hydrocarbons, fatty acid ethoxylates, and silicic acid, non-ionic
Binder	Acrylic binder, anionic/non-ionic
Colorant	CI Vat Blue 5

TABLE 4 Coating paste recipe.

Chemical	Amount (g)
Water	854
Superabsorbent polymers	20
Crosslinking agents	10
Binder	100
Antifoam	10
Dye solution (1%)	6
Total	1000

TABLE 5 Coating process conditions.

Knife gap (mm)	Knife angle	Number of passages	Scaling speed (m/min)	Drying temperature (°C)	Drying time (min)
0.50	0	1	2	130/140/150/160	5

TABLE 6 Coating process conditions.

Knife gap (mm)	Knife angle	Number of passages	Scaling speed (m/min)	Drying temperature (°C)	Drying time (min)[a]
0.25	0	1	2	150	3/4/5/6
0.50					4/5/6/7
0.75					5/6/7/8
1.00					9/10/11/12

[a] Different drying time ranges were used for each thickness due to the increase in drying time with the increase in coating thickness.

at four different temperatures (for each coating thickness). The adequacy of the drying temperature was determined by measuring the abrasion resistance after 2000 cycles using the Martindale abrasion and pilling tester. Static water absorption measurements were performed on the coated samples.

2.2.2 | Thickness, dry add-on, and abrasion resistance measurements

Before the samples were taken from the coated fabrics, they were conditioned for 24 h in the physical analysis laboratory according to TS EN ISO 139 (65% ± 2% relative humidity, 20 ± 2°C).

The thickness tests of the coated fabric samples were conducted using the R&B Cloth Thickness test device according to the ASTM D1777-96 standard. A fabric surface area of 1 cm^2 was selected as the test area. Five measurements were taken for each coating, and the average value was calculated to determine the fabric thickness. The measurements were performed with the device set to the lowest pressure value of 5 kgf/cm^2.

The abrasion resistance of the coated fabric samples was tested using the Martindale abrasion and pilling tester according to the TS EN ISO 12947-2 standard. The sample fabrics were cut into standardized dimensions (38 mm in diameter) and placed on the six heads of the testing device. They were subjected to abrasion under a 9-kPa load for 2000 cycles. The mass loss of the fabric after 2000 cycles was determined as a percentage using the following equation.

$$\text{The loss of mass}\,(\%) = (W_1 - W_2)/W_1 \times 100, \quad (1)$$

where W_1 (in grams) is the weight of the fabric before the test and W_2 (in grams) is the weight of the fabric after the test.

The amount of material coated on the fabric dry add-on was measured by the mass per unit area measurement according to the TSE-TS ISO 3801 standard. Samples measuring 10 cm × 10 cm were taken from each coated sample and weighed on a precision balance. The quantity of material transferred to the fabric was determined for each coating by taking five measurements and calculating the average using Equation (2)

$$\text{Dry add} - \text{on}\,(W_3) = W_2 - W_1, \quad (2)$$

where W_1 (in grams per square meter) is the weight of the uncoated reference fabric, W_2 (in grams per square meter) is the weight of the coated fabric sample, and W_3 (in grams per square meter) is the dry add-on amount (in grams per square meter).

The swelling behavior of SAP, an acrylamide/acrylic acid copolymer, used in the study at different pH ranges (4.5–10) was investigated by coating paste viscosity measurements with SOIF NDJ-8S Digital Viscometer.

2.2.3 | Water absorption capacity

Static water absorption measurements are based on the Bureau Veritas Consumer Products Services BV S1008 internal test method. It is aimed to determine the absorption capacity ratio of SAP-coated samples during immersion in pure water at different time intervals. SAP-coated samples cut into 10 cm × 10 cm dimensions were weighed and placed in plastic containers containing 500 mL of distilled water. The soaking times of the samples in distilled water were determined as 1, 5, 10, 20, 40, and 60 min. At the end of the period, the samples were removed and hung for 3 min, as shown in Figure 2, to remove excess water and then weighed. Four samples were tested for each pH (6–9) and the results were averaged to determine the absorbing capacity. The percent water absorption of the samples was calculated by the following

$$\text{Total absorptive capacity}\,(\%) = \frac{(W_2 - W_1)}{W_1} \times 100, \qquad (3)$$

where W_2 is the wet fabric sample weight (in grams) and W_1 is the dry fabric sample weight (in grams).

2.2.4 | Centrifuge retention capacity

This method was used to determine the liquid retention capacity of an SAP-coated fabric sample after it reached saturation and was subjected to centrifugation under controlled conditions. Centrifuge retention capacity (CRC) is a value that indicates how much liquid is retained by the swollen SAP after centrifugation. The samples whose absorption capacity was determined were subjected to the centrifuge test. The prepared samples were vertically placed in a basket with a height of 11 cm and a diameter of 10 cm, with the coated surfaces facing inward (Figure 3). The prepared samples were centrifuged at 1400 rpm, which corresponds to a centrifugal force of 110 G, for 3 min and then weighed. Four samples were tested to determine the CRC values, and the average of the results was taken. The CRC of the samples was calculated using the following equation

FIGURE 2 Static water absorption test apparatus. [Color figure can be viewed at wileyonlinelibrary.com]

$$\text{CRC}\,(\%) = \frac{(W_2 - W_1)}{W_1} \times 100, \qquad (4)$$

where W_1 is the initial weight (in grams) of the dry fabric sample and W_2 is the final weight (in grams) of the wet fabric sample.

3 | RESULTS AND DISCUSSION

3.1 | Thickness, dry add-on, and abrasion resistance results

The thickness (in millimeters) results and mass per unit area values (in grams per square meter) of the fabric samples coated at different coating thicknesses are graphically presented in Figures 4 and 5. According to graphics, as the coating thickness (distance between the knife and the fabric) increases, the thickness of the film on the fabric surface increases, leading to an increase in the thickness of the coated fabric and, consequently, the mass per unit area.

The thickness result of the samples studied at four different drying temperatures (130, 140, 150, and 160°C) while keeping the drying time (5 min) and coating thickness (0.50 mm) constant was obtained as 0.34 mm for all temperature values. Considering that the thickness of the

(a) (b)

FIGURE 3 Centrifuge tester. (a) General view. (b) View of test samples (blue-colored pieces) in the basket. [Color figure can be viewed at wileyonlinelibrary.com]

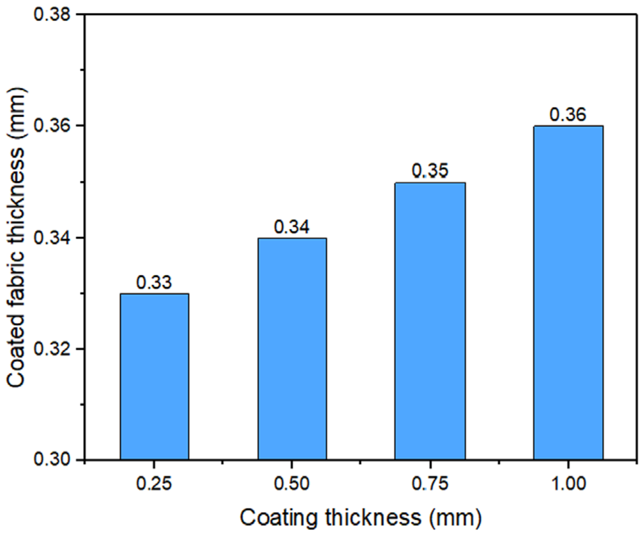


FIGURE 4 Thickness results of superabsorbent polymer-coated fabrics. [Color figure can be viewed at wileyonlinelibrary.com]

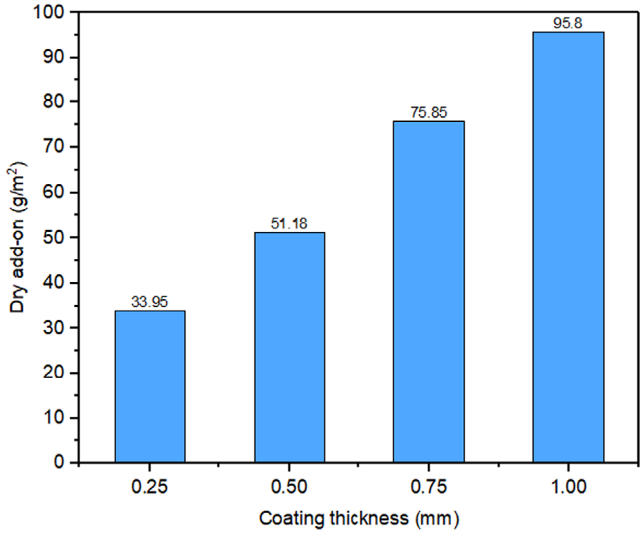


FIGURE 5 Dry add-on results of superabsorbent polymer-coated fabrics. [Color figure can be viewed at wileyonlinelibrary.com]

uncoated fabric is 0.30 mm, it can be concluded that there is no significant increase in fabric thickness at the studied concentration. This situation appears to be related to the high water content of the coating paste containing SAP polymer (approximately 85% on average). The low amount of SAP polymers remaining after the evaporation of water during the drying process forms an extremely thin layer on the fabric surface. Similarly, the amount of coated material per unit area (i.e., dry add-on) was determined to be an average of 51.18 g/m^2 for each drying temperature. These results indicate that the different drying temperatures applied to the coated fabric samples did not cause any significant changes in the fabric thickness or the mass per unit area of the coated material.

The thickness (in millimeters) results and dry add-on values (in grams per square meter) of the fabric samples coated at different coating thicknesses are graphically presented in Figures 4 and 5. According to graphics, as the coating thickness (distance between the knife and the fabric) increases, the thickness of the film on the fabric surface increases, leading to an increase in the thickness of the coated fabric and, consequently, the dry add-on.

Different trials were conducted to determine the appropriate drying-fixation times for various coating thicknesses. The average results of the abrasion test after 2000 cycles on the coated samples using the Martindale device are presented in Table 7. Taking into consideration that the weight loss will be at its lowest rate after the fixation process and remain constant with increasing times, suitable drying-fixation times for different coating thicknesses have been determined as follows: 4 min for 0.25 mm, 6 min for 0.50 mm, 7 min for 0.75 mm, and 10 min for 1.00 mm.

3.2 | Viscosity change depending on the pH of the coating paste

It is well known that SAP is highly sensitive to the pH of the liquid they are added to and the presence of

TABLE 7 Weight loss[a] (in percentage) results of coated fabrics after abrasion test.

Dry add-on (g/m^2)							
33.95		51.18		75.85		95.80	
Time (min)	Abrasion (%)	Time (min)	Abrasion (%)	Time (min)	Abrasion (%)	Time (min)	Abrasion (%)
3	0.656	4	0.872	5	7.104	9	0.720
4	0.203	5	0.443	6	1.733	10	0.361
5	0.202	6	0.205	7	0.667	11	0.358
6	0.202	7	0.202	8	0.661	12	0.352

[a] Weight loss (in percentage) result of uncoated-woven polyester fabric after abrasion test: 0.

electrolytes in the environment, and their swelling performance can vary dramatically.[19] Since the swelling degree of SAP in water directly determines the viscosity of the coating paste, viscosity changes have been investigated in coating formulations containing SAP with different pH values. The viscosity changes for the coating paste prepared at 12 different pH values are given in Figure 6. As the pH value of the coating paste increases from 4.5 to 6.5, it can be observed that the viscosity significantly increases (from 750 to 8300 cP). In the pH range between 6.5 and 8.5, the viscosity of the coating paste remains stable (8500–9000 cP), and there is no significant change. The obtained results indicate that the swelling ratio significantly decreases as the pH value is lowered from the neutral region to the acidic region, while it remains high and stable under neutral-weak alkaline conditions. These results are also consistent with the findings of previous studies performed by Lenji et al.[20] and Zhang et al.[21]

3.3 | Water absorption test results

The results of the static water absorption test of the coated samples at four different coating thicknesses are given in Figure 7. It can be observed that when the coating thickness increases from the lowest thickness of 0.25 mm to the highest thickness of 1.00 mm, the water absorption capacity also significantly increases. As shown in Figure 5, the amount of SAP polymer per unit fabric area increases proportionally with the increase in coating thickness, leading to this expected increase in water absorption rate.

The static water absorption capacities of the fabrics coated with coating pastes prepared at a constant viscosity (~8750) but at four different pH values were tested depending on time. The values in Figure 8 show that the sample coated with the paste at pH 6 had the lowest water absorption capacity, and the capacity increased until pH 8, and there is no significant difference between pH 8 and 9. This result does not fully correspond to Figure 6, which shows the free polymer powders' viscosity (swelling) capacity depending on the pH value. It is thought that this discrepancy may be related to the binder and cross-linker added to the coating paste, making more crosslinking in the acidic region.[22] Therefore, water absorption is expected to be lower at low pH values where more cross-linking occurs.

The easiest way to increase the water absorption capacity of fabrics coated with SAP is to increase the SAP concentration in the coating paste. However, as the SAP concentration increases, the viscosity also rapidly increases, and beyond a specific concentration, it becomes impossible to achieve a smooth coating due to high viscosity. To overcome this problem, two different coating pastes with a similar viscosity (~8750 cP) but different concentration values were prepared using different pH values (pH 5 and 7). The results of the static water absorption test of the samples coated with the coating paste with 2% and 2.8% SAP concentration and a thickness of 0.50 mm are shown in Figure 9. As

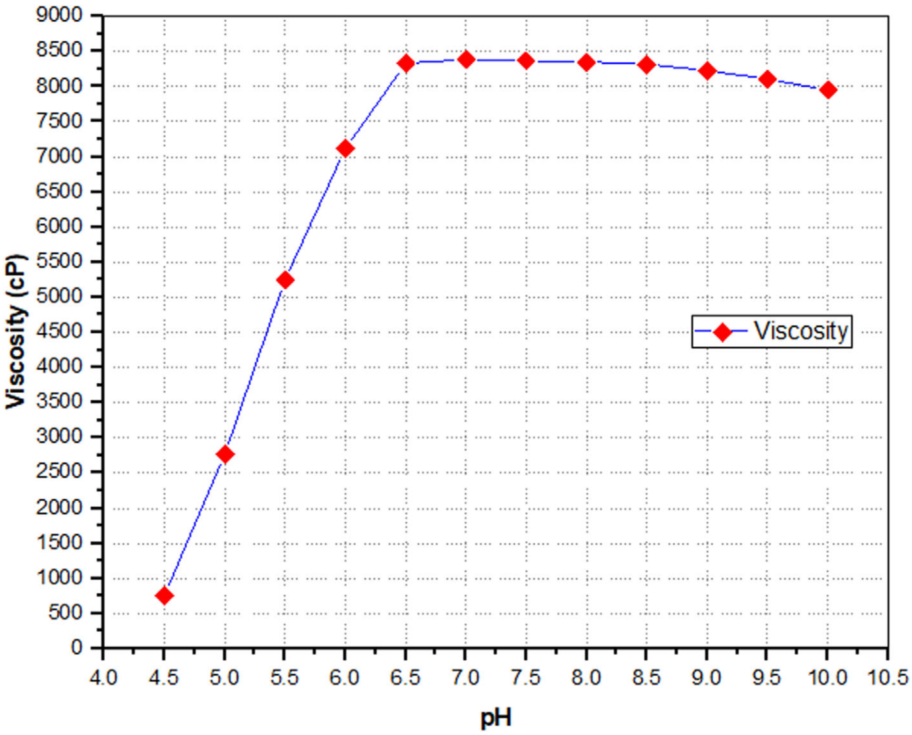


FIGURE 6 Viscosity change test results. [Color figure can be viewed at wileyonlinelibrary.com]

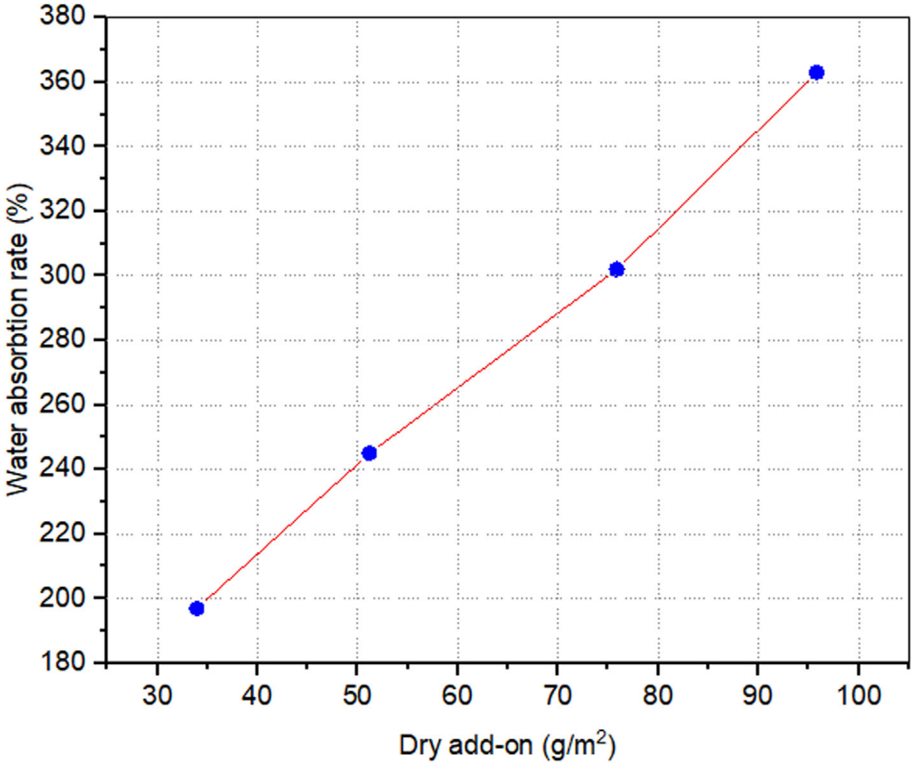


FIGURE 7 Static water absorption capacity (in percentage) test results depending on dry add-on amounts. [Color figure can be viewed at wileyonlinelibrary.com]

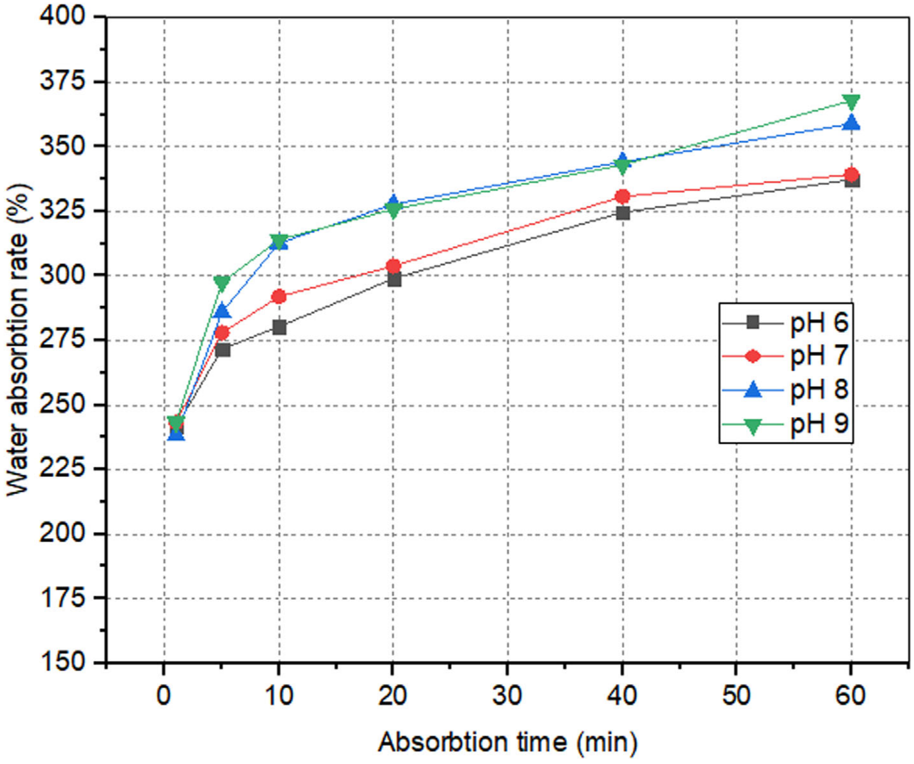


FIGURE 8 Static water absorption capacity (in percentage) test results. Water absorption rate of uncoated-woven polyester fabric: 57.89%. [Color figure can be viewed at wileyonlinelibrary.com]

expected, it can be seen that the water absorption rate increases as the SAP concentration increases. This result demonstrates that pH value can be used as a parameter to increase the SAP concentration in the coating paste.

3.4 | Water retention capacity test results

The "CRC test" is one of the commonly used standard tests, particularly in the hygiene sector, to determine the water

FIGURE 9 Static water absorption capacity (in percentage) test results. [Color figure can be viewed at wileyonlinelibrary.com]

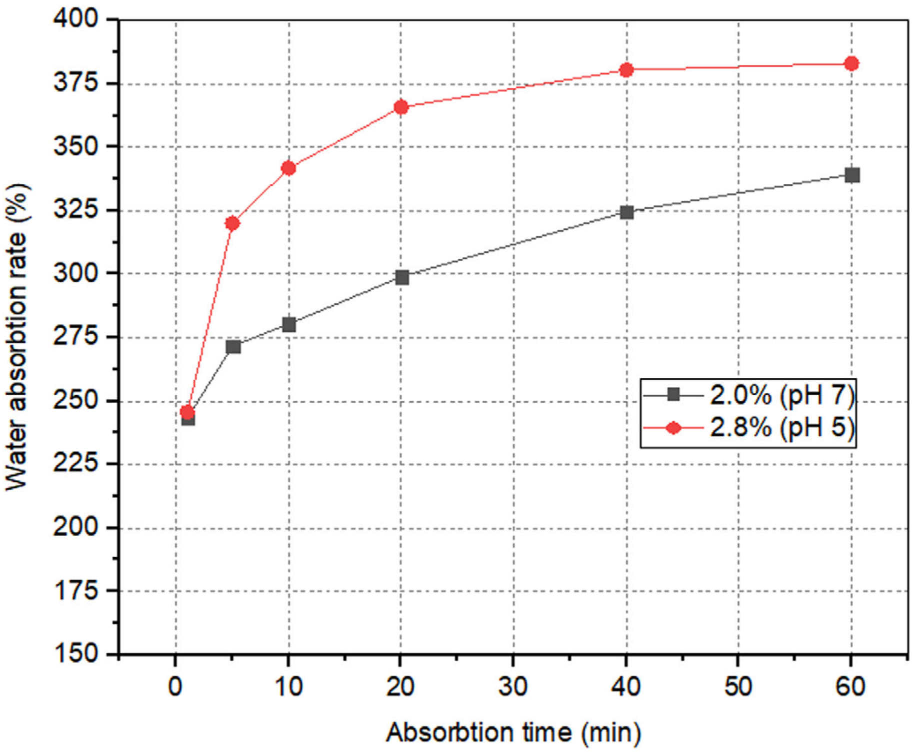
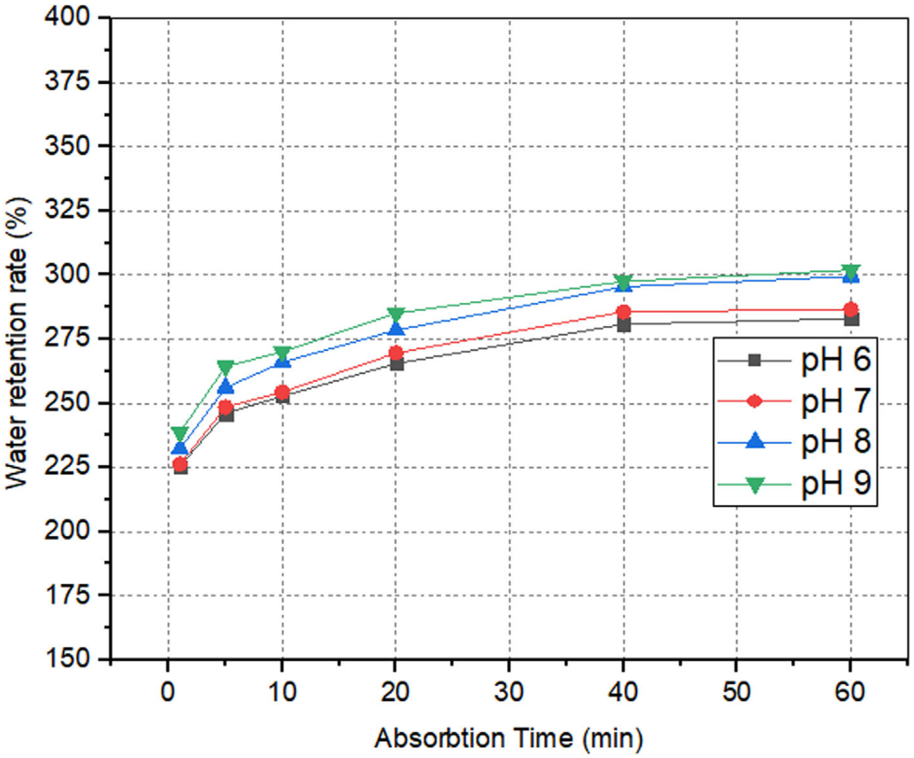


FIGURE 10 Centrifuge water retention capacity (in percentage) test results. [Color figure can be viewed at wileyonlinelibrary.com]



retention capacity of swollen SAP after centrifugation.[23,24] In this section, CRC tests were conducted on samples coated with a coating paste prepared with four different pH values and subjected to water immersion for six different durations (1, 5, 10, 20, 40, and 60 min). The test results obtained are presented in graphical form in Figure 10.

As seen from the figure, it can be observed that the water absorption capacity generally increases as the soaking time increases from 1 to 40 min for all pH values. However, if the soaking time is extended up to 60 min, there is no significant increase in the centrifuge water retention capacity.

This result indicates that the absorption/swelling of SAP is largely completed at the end of the 40-min soaking time for all pH values, and the additional water taken is present as free water (surface water) on the surface of the coated polymer layer and the fibers that make up the fabric. Because it is known that as a result of centrifugation processes applied as pre-drying in the drying processes of textile materials, only the free water on the material can be removed, while the absorbed water can only be removed by thermal drying processes (via evaporation).[25,26]

On the other hand, as the pH value increases from 6 to 9, specific increases occur in water retention rates corresponding to all water absorption time values. It was concluded that this situation, parallel with the static water absorption rates, may be related to the same reason (less cross-linking at higher pH values).

4 | CONCLUSION

This study includes research on the application of water-based coating pastes containing micronized SAP powders to PES-woven fabric surfaces. The effect of the SAP transferred to the fabric by the coating technique on the water absorption behavior and performance of the fabric has been revealed by optimizing the drying-fixation temperatures and duration, SAP concentration, coating thicknesses, and pH values.

It has been seen that the required drying-fixing times increase significantly as the amount of water that needs to be evaporated from the fabric increases with the increase in the coating thickness values given as the distance between the fabric and the blade. In addition, depending on the increase in coating thickness, the density of SAP coated on the fabric also increases, and as a result, the static water absorption capacity increases at a similar rate. It has been revealed that pH value is a considerable parameter that needs to be controlled in terms of viscosity adjustment in the preparation of coating pastes containing SAP, and the viscosity is largely stable in the pH range of 6.5–8.5. At the same time, the pH value of the coating paste containing SAP has a remarkable effect on the static water absorption capacities and centrifugal water retention rates of the coated fabrics; in general, maximum water absorption/holding capacity is obtained between pH 8 and 9. When fabrics coated with SAP polymers came into contact with water, they absorbed water rapidly within the first 10 min, and then the absorption rate slowed down. However, the fabrics continued to absorb water for 60 min.

The study concluded that the water-based coating paste containing SAP can be successfully applied to woven fabric surfaces using the knife-over-roll coating technique, and this method can significantly increase the water absorption capacities of hydrophobic textile materials such as PES. The experimental studies revealed that the coating recipe formulations and process conditions applied can be used for nonwash durable (single-use) or partially wash-resistant products. The project studies are continuing, and in the following sections, the necessary formulation and process conditions will be developed for wash-durable (reusable) coating.

AUTHOR CONTRIBUTIONS

Kadir ÖZAN: Data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); resources (equal); visualization (equal); writing – original draft (equal). **Mehmet Kanik:** Conceptualization (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); writing – original draft (equal); writing – review and editing (equal). **Sude Seyda Özer:** Data curation (supporting); formal analysis (supporting); resources (supporting); supervision (supporting); visualization (supporting).

ACKNOWLEDGMENTS

This study was carried out within the scope of a project titled TUBITAK-1505, "Development of Surfaces with High Liquid Absorption Capacity with Super Absorbent Polymers with the Help of Coating Techniques" (5220066). The authors thank TUBITAK (Turkish Scientific and Technical Research Council) for financial support and project partner PAKTEN Inc. We would also like to thank Kirayteks for providing the polyester fabric and Rudolf & Duraner for supplying the coating chemicals.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: K. Özan, M. Kanik, S. S. Özer, *J. Appl. Polym. Sci.* **2024**, *141*(4), e54837. https://doi.org/10.1002/app.54837