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Influence of superabsorbent fibre in cotton web on absorption of saline solution

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Three types of nonwoven structures, viz. one mono-component (100 % cotton) and two bi-components (homogeneously dispersed fibres and layer-wise assembled fibres) have been prepared and then evaluated for absorption performance. The addition of superabsorbent (SAF) fibres into the nonwoven structure marginally improves the absorption capacity of the homogeneously blended structure in comparison to the 100 % cotton web. The liquid (synthetic urine) retention of the cotton web is found to vary between 45 % and 65 %, depending upon the external pressure. The SAF, however, increases the retention capacity significantly. Amongst all the structures, the retention of layered structure is found to be superior to the rest.

Keywords: Absorption, Cotton web, Nonwoven, Pore size distribution, Superabsorbent fibres, Saline solution

1 Introduction

Fibrous webs are used for liquid absorption in many products, such as diapers, wound dressings, mops, face masks, incontinence products, etc.[1,2]. Absorption and retention are the essential attributes of absorbent products. Cellulosic fibres, such as pulp, viscose rayon and cotton, are some of the well-known absorbent materials. The porous nature of the web causes the liquid to penetrate the structure due to capillary tension and thereafter retained in the void spaces within the structure. However, fibre-based incontinence products are bulky with limited absorption rate, absorption, and retention capabilities. There have been many efforts to make the absorbent product lighter without compromising its absorption performance by chemically modifying the fibre constituents[3-6].

In the early 1960s, synthetic polymeric materials (superabsorbent polymer known as SAP) with prodigious absorption capacity were developed[7–9]. These materials can absorb fluids several times of their weight. About 95% of superabsorbent in the marketplace are cross-linked, polyacrylic acid with sodium[10]. Due to three-dimensional cross-linked hydrophilic polymeric chains, the polymer doesn’t dissolve at all[11]. The liquid absorption within the polymer occurs due to the diffusion phenomenon[12] and can immobilise the fluid without releasing it, even under pressure. Polymers are not only used in absorbent products but also in agriculture, pharmaceutics, separation technology, water-swelling rubbers, soft actuators/valves, electrical cables, and construction sectors[13].

Superabsorbent polymers are available in powder, granules, and fibre forms. In most commercial products, the SAP is added in powder or granule form. However, the disadvantage in powder form is the non-homogenous mixing with constituent fibres, non-uniform distribution of the granules/particles within the structure and the possibility of distribution in lump form in many areas. Other than that, they are abrasive and may create a rough and harsh handle. On the contrary, SAP in the fibre form has certain advantages, such as (i) fast liquid absorption, (ii) better integration within the structure, and (iii) being less likely to migrate on its own during handling. They not only make the product less bulky but also more efficient in liquid absorption[14].

Many researchers have blended the superabsorbent materials with other fibres to fully utilize their absorbency power. Shanmugasundaram & Gowda[15] have blended the superabsorbent polymer with the cotton/bamboo fibres and found better liquid absorption capacity. Das *et al.*[16] have prepared nonwovens using superabsorbent fibres and polypropylene with varying cross-sectional geometries. In layer-wise mixing, higher sorption capacity and lower sorption rate were observed than that of the randomly mixed structures. Kim *et al.*[17] have studied the liquid absorption property of nonwoven prepared by mixing superabsorbent fibres (SAF) with hollow viscose rayon (HVR).

However, superabsorbent polymers/fibres are non-biodegradable and take years to decompose completely. The sustainable solution is to identify

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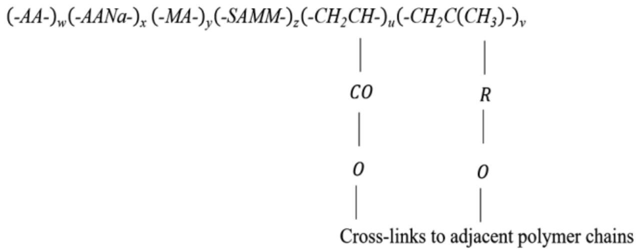
alternative biodegradable superabsorbent material[18-20]. Castrillon *et al.*[21] have used poly (γ-glutamic) acid (PGA) cross-linked by L-lysine and Gellan gum with Jeffamine130 as a biodegradable substitute for SAP materials. Dutkiewicz[2] developed biodegradable superabsorbent materials using chitosan salts. Another possible solution could be, minimising the weight proportion of SAP in the absorbent product. Sayeb *et al.*[22] studied the influence of superabsorbent polymer (SAP)/fluff ratio, compression, and porosity on the absorbency performance by adding SAP up to 30% and found that the absorption capacity increases fast till 10 % addition and thereafter the rise was slow.

The absorption capacity, rate, and retention under varying pressure are essential functional attributes of any absorbent product. Though superabsorbent fibres can absorb many times of their weight, there is an associated danger of blocking many pores in blended structures due to excessive swelling of the fibres or granules, thus decreasing the net liquid absorbency[16]. This can be obviated by using the correct percentage of SAF and its distribution within the structure for optimum performance. The cross-sectional distribution within the structure plays a significant role in the absorbency performance of any composite web[16]. The present paper reports on the absorption performance of SAF: cotton blended needle-punched nonwoven structures. Structural variation in terms of the placement of SAP fibres within the structure is also investigated.

2 Materials and Methods

2.1 Sample Preparation

OASIS Superabsorbent fibre having 1.40 g/cc density and 50 mm in length was used. It has an absorption capacity of 35 g/g. The raw materials used for manufacturing superabsorbent fibre (SAF) are acrylic acid, methyl acetate, special acrylate or methacrylate monomer. The chemical structure of OASIS SAF is provided below:



$$(\text{-}AA\text{-})_w(\text{-}AANa\text{-})_x(\text{-}MA\text{-})_y(\text{-}SAMM\text{-})_z\underset{\substack{|\\ CO\\ |\\ O\\ |}}{(\text{-}CH_2CH\text{-})_u}\underset{\substack{|\\ R\\ |\\ O\\ |}}{(\text{-}CH_2C(CH_3)\text{-})_v}$$

Cross-links to adjacent polymer chains

Here,

AA = {-$CH_2CH(COOH)$} from acrylic acid

AANa = {-$CH_2CH(COONa)$} from acrylic acid and NaOH

MA = {-$CH_2CH(COOCH_3)$} from methyl acrylate

R = (-$COOCH_2CH(CH_3)$ –

The values of w, x, y and z depend on the quantities of monomer raw materials used.

The values of u and v depend on the amount of heat treatment applied.

The OASIS superabsorbent fibres were mixed with 6 micronaire cotton (variety S-6) of 20.87 μm mean length. The absorption capacity of cotton fibres is 16.6 g/g. The cotton fibre was scoured using (4 % o/w) NaOH and lisapol at 100°C for 60 min. The fibres were then thoroughly washed to remove any traces of NaOH. The wet fibres were dried for 24 h at 25°C room temperature. The web from the CIRCOT TRYTEX miniature carding machine was consolidated by DILO needle punching on a nonwoven machine. The needles used on the DILO needle punching machine are double reduction barbed needles with 32-40 gauge, 3 inch needle length in RF Barb style.

Two different web structures were produced (Fig. 1). In the first case, scoured cotton fibres were mixed manually with superabsorbent fibres in varying proportions (10, 20, 30 and 40 %) and processed on carding machine to produce the web of 400 g/m^2. In the second case, a sandwich layered superabsorbent fibres and cotton were produced. The superabsorbent fibre layer was in between two cotton fibre layers. Cotton and superabsorbent fibres of appropriate quantity were taken and processed sequentially on a miniature carding machine to produce such a structure. The weight proportion of the two fibres (SAF: cotton) was taken as 40:60. The webs were wound on a drum on top of each other. The loose SAF: cotton composite web was torn along a line and taken to the needle punching section of a nonwoven machine and punched with 50 punches/cm^2, keeping a penetration depth of 10 mm.

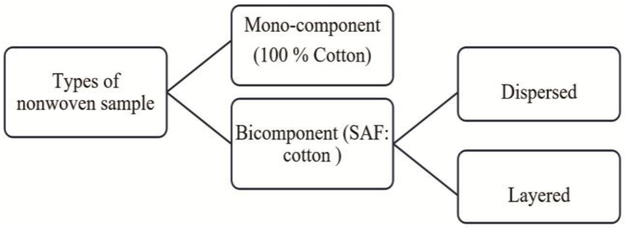


Fig. 1 — Types of samples

2.2 Test Methods

2.2.1 Measurement of Thickness and Areal Density

The thickness of the webs was measured by an Essdiel thickness gauge tester as per ASTM D1777-96. The areal density (mass per unit area) was determined according to ASTM D3776/D3776M. A minimum of ten readings were taken for each sample and average values were calculated.

2.2.2 SEM Image of Fabric Cross-section

All the nonwoven webs were gold-plated before SEM testing. The samples were gripped firmly and then cut across their width using a surgical knife. The cross-sections were viewed under a scanning electron microscope SEM EVO18 Zeiss. The acceleration voltage of the work was 22 kV. Suitable images were captured for further analysis.

2.2.3 Determination of Pore Size Distribution

Porolux 100, based on the gas-liquid displacement principle[23] has been used to evaluate the pore size distribution. It is used to rapidly measure through-pores in materials such as membranes, filters, paper, hollow fibres, and many other applications. Circular samples (2.1 cm in diameter) were taken and wholly immersed for 30 s in the low surface tension wetting liquid (Porefil; 16.0 dyne/cm). The samples were placed in the sample holder. A gradual rise in gas pressure was applied to force the liquid to move out completely from the sample. This method measures the bubble point, most minor pore diameter (SP), mean pore flow (MFP), cumulative filter flow, pore size distribution, etc.

2.2.4 Determination of Absorption Capacity and Retention

Circular samples of 5 cm diameter were cut from different parts of each fabric and weighed (W_d). Each specimen was first immersed in saline solution for 60 s and then hung in free air vertically for 120 s to drain excess water. Finally, wet samples were reweighted to determine the wet weight of the samples (W_w).

The water absorption capacity (WAC, g/g) of the samples was calculated as:

$$\text{Absorption capacity (g/g)} = \frac{(W_w - W_d)}{W_d} \qquad ...(1)$$

The water was expelled from the wet samples by placing dead weights (Fig. 2). First, the dead weight of 500 g was placed on the sample and waited for 240 s to allow the water to squeeze out. The load put earlier was removed, and the weight of the wet sample (W_{f1}) was measured on an electronic balance. The sample was taken back, and an additional load of 500 g was placed on it for duration of 240 s. The load was removed again, and the sample weight (W_{f2}) was measured. The process was repeated by adding 500 g load successively and measuring the sample weights ($W_{f3,}$ and W_{f4}). Therefore,

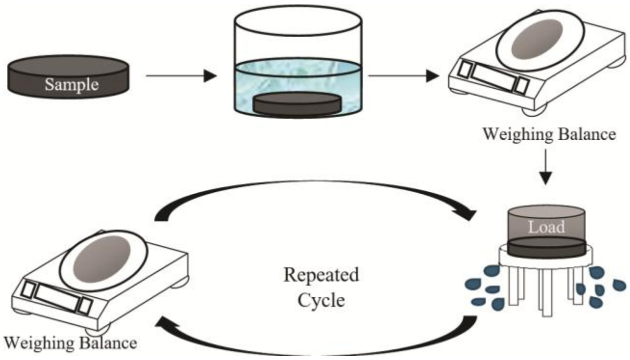


Fig. 2 — Retention test method

$W_w - W_d$ = Saturated water content in the sample.
$W_{fi} - W_d$ = Water retained under a certain load (i = 1, 2, 3, 4)

The retention % at different loads is:

$$\text{Retention (\%)} = \frac{\text{Weight of water retained under pressure}}{\text{Weight of water absorbed at no load}} = \frac{W_{fi} - W_d}{W_w - W_d} \times 100 \qquad ...(2)$$

2.2.5 Determination of Expected Absorption Capacity

The absorption capacities of dispersed webs were estimated by following mixture rule[24]:

$$\text{Expected AC}_{\text{mix web}} = \left(\frac{p_1}{100} \times AC_{Cotton} + \frac{p_2}{100} \times AC_{SAF}\right) \qquad ...(3)$$

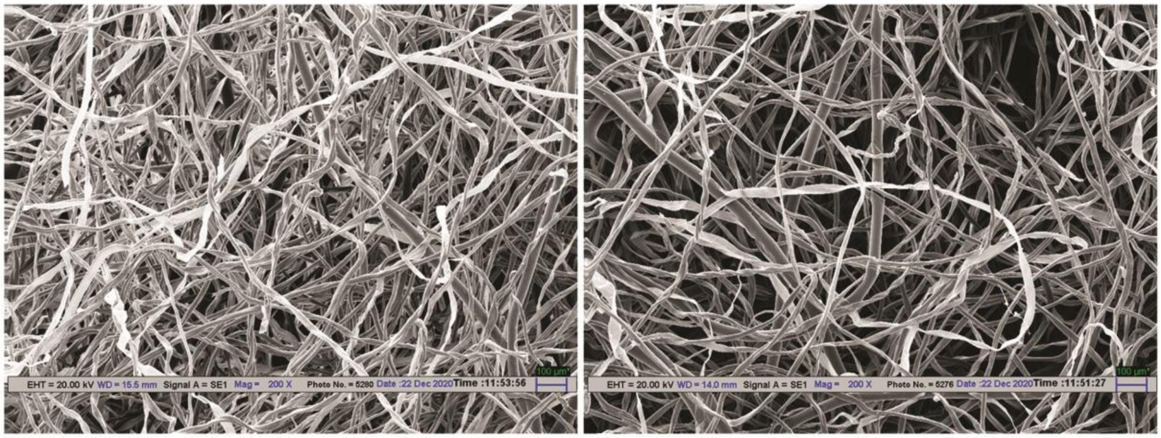
where p_1 is the weight % of cotton; p_2, the weight % of SAF; AC_{Cotton}, the absorption capacity of cotton; AC_{SAF}, the absorption capacity of SAF; and AC_{mix}, the absorption capacity of the dispersed (mixed) web.

3 Results and Discussion

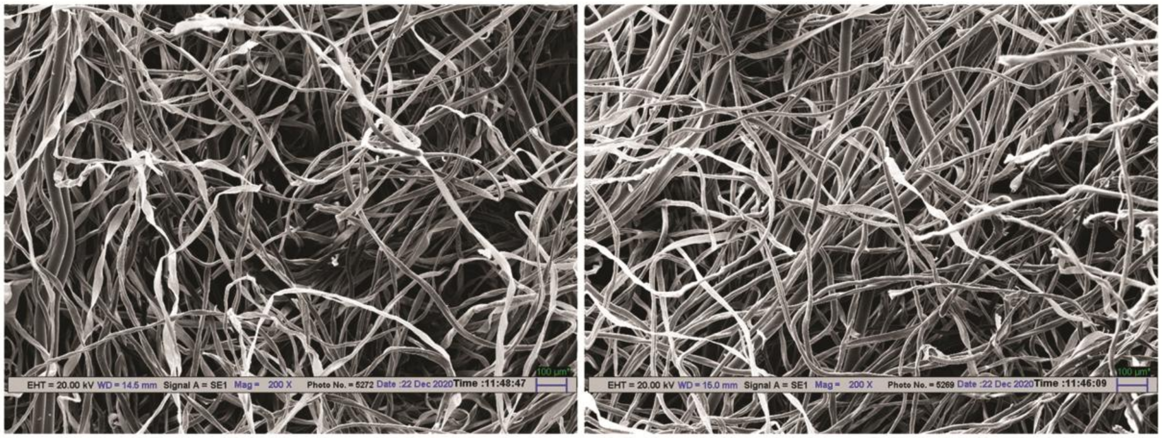
3.1 Absorption Capacity of Dispersed Structure

Figure 3 shows the SEM images of the cross-sectional view (×200) of nonwoven webs produced.

The cotton fibres (convoluted ribbonlike) and SAF (rod like) are visible in the images. With increasing the SAF percentage (30 % and 40 %), more SAF fibres are seen on the top surface of the webs. The liquid absorption capacity of the dispersed webs is



SAF:cotton (90:10) SAF:cotton (80:20)



SAF:cotton (70:30) SAF:cotton (60:40)

Fig. 3 — SEM images (×200) of SAF: cotton dispersed structure

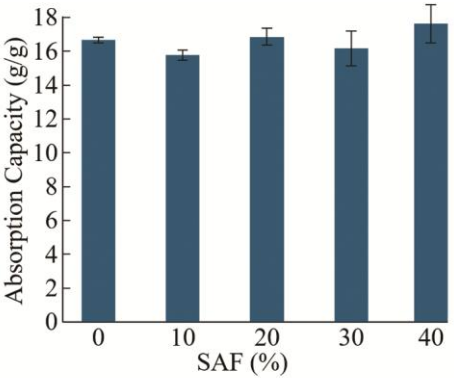


Fig. 4 — Liquid absorption capacity (g/g) of dispersed nonwoven webs

shown in Fig. 4. The web consisting of 100 % cotton fibres has a capacity of 16.6 g/g. With the addition of SAF (up to 40 %), the capacity changes to 17.6 g/g, i.e. an increase of only 1 g/g. This shows a marginal increase in the absorption capacity.

This is due to the excessive swelling of SAF fibres, leading to gel-formation that blocks the pores within the structure. The lower absorption capacity and rate are also due to the saline nature of the liquid.

The same sample when tested by DI water gives a very high absorption capacity (50 g/g); saline liquid shows 20g/g. It appears that the salt solution brings down absorbency phenomenally.

It has been stated by many researchers[10,25] that the addition of salt in absorbing liquid leads to a reduction in the absorption capacity of superabsorbent polymer. This is due to a reduction in the swelling capacity of the polymer. The absorption rate, however, may either increase or decrease depending on the percentage of superabsorbent in the blend. It, therefore, appears that the saline liquid absorption properties of fibrous web can be tailored by correctly choosing the SAF percentage in the nonwoven.

3.2 Comparison between Actual and Expected Absorption Capacities

The actual absorption capacities of dispersed webs are compared with expected absorption capacities based on the rule of mixture. The expected and actual absorption capacities are linearly related. The relationship can be expressed by the following equation:

$$\text{Actual absorption capacity} = 0.40 \times \text{Expected absorption capacity} + 8.57 \qquad \ldots(4)$$

The r^2 value (0.81), indicates a reasonably good fit. The mixture rule overestimates the absorption capacity. This is so as it does not consider the swelling of SAF, which leads to blockage of pores with adverse consequences on absorption.

3.3 Web Thickness and Pore Size Distribution

After the absorbency test, the wet samples are oven-dried at low temperatures. Care has been taken to ensure that the structure is not disturbed during handling. SAF fibres swell phenomenally after absorption of water. The swelling of SAF will gradually increase the volume of the web. However, the SAF are intertwined surrounding cotton fibres due to needle punching of the web. The anchored cotton fibres will resist swelling of the structure. The net effect will depend upon the dominance of one factor over the other.

After completion of absorption tests, the web thickness for all the samples is increased (Table 1), except 100 % cotton nonwoven. The thickness increase reflects the dominance of the swelling phenomenon of wet SAF fibres. This swelling action rearranges the cotton fibres within the structure. Pore size distribution affects absorption rate as well as retention**.** Therefore, pore size distributions of the webs before and after the absorbency tests are carried out. Thus, the MFP (mean flow pore), SP (smallest pore diameter) and overall pore size distribution change after the absorption test (Table 2).

It can be seen that the addition of 10 % SAF decreases both MFP and SP values. At 40 % SAF, only the MFP increases. With the swelling of SAF, many pores within the structure are blocked due to the well-known gel formation of the SAF. The volume of the web is increased by 79 % (Table 2). As a result, pore size (MFP and SP) decreases.

3.4 Retention

The liquid retention at different external pressures is shown in Fig. 5. Following observations can be made:

- Retention % decreases fast initially and gradually levels off with the increase in external pressure for all the samples.
- Retention% of the dispersed (SAF: cotton) samples is more than the 100 % cotton webs.
- At any external pressure, the retention increases with an increasing % of SAF in the mixture.
- With 40 % SAF in the mixture, the retention capability reduces from 85 % to 66 %, with increased external pressure. However, for 100 % cotton web, retention% changes from 68 % to 45 %.

Therefore, it can be seen that though there is no significant change in absorption capacity on increasing the % superabsorbent fibres in the mixture, a remarkable gain can be observed in retention. This is due to the exceptional liquid-locking property of superabsorbent fibres due to gel formation.

3.5 Absorption and Retention of Layered Structure

Figure 6 shows the SEM images of the layered structure where the SAF layer is seen sandwiched

Table 1 — Influence of liquid absorption on thickness of nonwoven (SAF:cotton) web

SAF in blend, %	Thickness mm		Thickness change*, %
	Dry state	Wet state	
0	5.94	4.94	-16.83
10	4.18	5.24	+25.19
20	4.40	6.17	+40.15
30	3.59	5.83	+62.29
40	3.47	6.23	+79.30

*(+) indicates structure expansion. (-) indicates structure collapse.

Table 2 — Pore size (μm)

Sample	10 % SAF		40 % SAF	
	MFP	SP	MFP	SP
Before absorbency test	28.25	7.20	26.47	5.90
After absorbency test	24.25	3.18	28.96	4.02

*MFP – Mean flow pore, SP – Smallest pore.

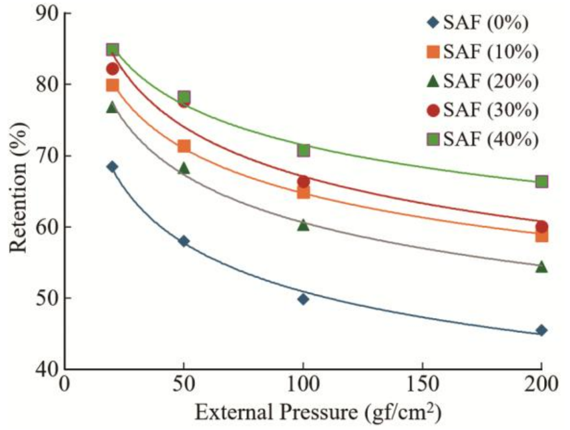


Fig. 5 — Retention (%) of various SAF: cotton nonwovens

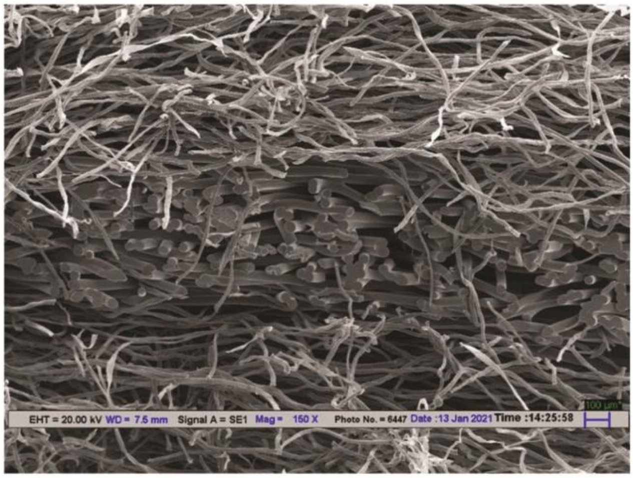


Fig. 6 — Cross-sectional view of layered structure

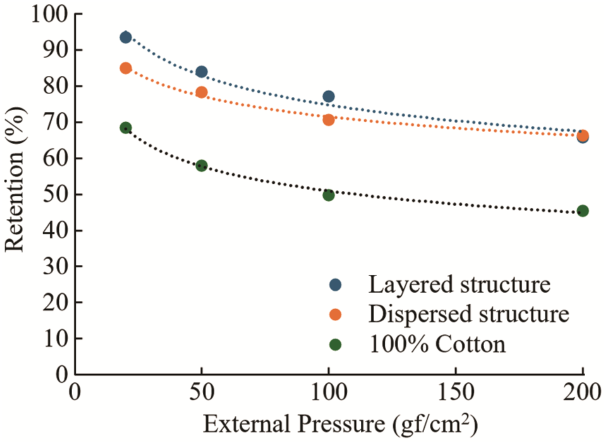


Fig. 7 — Retention (%) versus external pressure

between two cotton layers. The SAF is 40 % by weight of the total assembly weight.

The absorption capacities of layered, dispersed and 100 % cotton structures are 14.73 g/g, 17.63 g/g and 16.66 g/g, respectively. The layered structure shows the lowest absorption capacity in comparison to both 100% cotton and homogeneously mixed SAF: cotton web.

Figure 7 shows retention % at various external pressures. The following observations are made:

- The liquid retention decreases with an increase in external pressure for all structures.
- The retention of webs containing SAF is much greater than 100 % cotton.
- Though in the beginning, a difference (8 %) in the liquid retention % between the dispersed and layered structure of SAF: cotton webs are seen, it gradually reduces with external pressure. It almost becomes nil in the higher pressure range.
- Over the pressure range studied, the retention reduces from 93.5 % to 65.7 % for the layered structure and 84.9 % to 66.4 % for the dispersed structure with an increase in pressure.
- For 100 % cotton, the retention lies between, 68.4 % and 45.5 %, depending upon the external pressure.

These results, therefore, indicate that though absorption capacity does not improve in the case of the layered structure, a remarkable gain in liquid retention (36 %) is achieved over 100 % cotton web.

Both lower absorption capacity and higher retention for layered structure can be attributed to SAF's gel-blocking phenomenon. After absorbing the liquid through diffusion, the SAF fibres keep on swelling till they reach an equilibrium level. Due to the needle punching process, many cotton fibre ends are pushed within the structures, which act as tying points. The free swelling of SAF gets restricted due to cotton layers on both sides. The little swelling of SAF tightens the structure and reduces the porosity of the adjacent cotton layers. As a result, the cotton layers absorb less quantity of liquid, and the overall absorption capacity of the layered structure becomes less than the other two web structures.

The liquid held in between the pores of cotton fibres is expelled quickly under pressure. However, the water bound by SAF in the form of a hydrogel can only move through molecular diffusion, which is a slow process. The viscous hydrogel cannot pass through the pores of the cotton layers surrounding it even under pressure. According to Staples[10], osmotic pressure can be quite high for superabsorbent gel, allowing high fluid retention under external load. Hence, more liquid is expected to be retained when SAF is used.

4 Conclusion

The absorption capacity of SAF mixed cotton nonwoven fabric reduces from 50 g/g in DI water to 18.86 g/g in saline solution. There is marginal improvement in the saline solution absorption capacity of 100 % cotton and 40 % SAF mixed cotton nonwoven fabric. The liquid retention %, however, increases significantly by adding even only 10 % SAF to cotton.

The coefficient of determination of absorption capacities estimated following the rule of mixture and the actual observed is 0.81. The gel-blocking of pores by the SAF fibres in a wet state reduces the absorption capacity of the nonwoven in comparison to theoretically estimated.

The absorption capacity of the layered SAF: cotton structure is lower than the SAF: cotton (homogenous mixture). The liquid retention capacity of SAF mixed cotton web is always more than that of 100 % cotton web, irrespective of external pressure. The advantage of a higher retention % of layered structure over a homogeneous mixture seen at low external pressure gradually reduces at high pressure.

Hence, a minimum of 10 % SAF blended in layered form with cotton is sufficient to enhance the overall absorption performance in any liquid-absorbent products.

References

1 Hong K H, Kim S C, Kang T J & Oh KW, *Text Res J,* 75 (2005) 544.
2 Dutkiewicz J, *Autex Res J,* 2 (2002) 153.
3 Bidgoli H, Zamani A, Jeihanipour A & Taherzadeh MJ, *Fibers Polym,* 15 (2014) 431.
4 Hubbe M A, Ayoub A, Daystar J S, Venditti R A & Pawlak J J, *Bioresour,* 8 (2013) 6556.
5 Kabir S M F, Sikdar P P, Haque B, Bhuiyan M R, Ali A & Islam M N, *Prog Biomater,*7 (2018) 153.
6 Brodin F W & Theliander H, *Bioresour*, 7 (2012) 1666.
7 Mark E, *Prod Dev Scentist SAP*, 13 (2004) 1.
8 Athawale V D & Lele V, *Starch/Stärke*, 53 (2001) 7.
9 Wilson P A & Dallas M J, *Pediatr Dermatol*, 7 (1990) 179.
10 Chatterjee P K & Gupta BS, *Absorbent Technol* (Elsevier Ltd), 2002.
11 He G, Ke W, Chen X, Kong Y, Zheng H, Yin Y & Cai W, *React Funct Polym*, 111 (2017) 14.
12 Bartkowiak G, *Fibres Text East Eur*,14 (2006) 57.
13 Zohuriaan-Mehr M J, Omidian H, Doroudiani S & Kabiri K, *J Mater Sci*,45 (2010) 5711.
14 Kakonke G, Tesfaye T, Sithole B & Ntunka M, *Int J Chem Sci*, 17 (2019) 1.
15 Shanmugasundaram O L & Gowda R V M, *Indian J Fibre Text Res,* 35 (2010) 201.
16 Das D, Rengasamy R S & Kumar M, *Fibers Polym,* 14 (2013) 1165.
17 Kim G H, Youk J H, Kim Y J & Im J N, *Fibers Polym,* 17 (2016) 1104.
18 Lacoste C, Lopez-Cuesta J M & Bergeret A, *Eur Polym J,* 116 (2019) 38.
19 Djafari Petroudy S R, Ranjbar J & Rasooly Garmaroody E, *Carbohydr Polym*, 197 (2018) 565.
20 Capezza A J, Newson W R, Olsson R T, Hedenqvist M S & Johansson E, *ACS Sustain Chem Eng,* 7 (2019) 4532.
21 Castrillon N, Echeverria M, Fu H, Roy A & Toombs J, *Commodity Polymer Project, Berkeley* (University of California), 2019.
22 Sayeb S, Ladhari N, Hassen M Ben & Sakli F, *J Appl Sci*, 7 (2007) 1953.
23 Dhiman R & Chattopadhyay R, *J Text Inst,* 112 (2021) 996.
24 El Hachem Z, Célino A, Challita G, Moya M J & Fréour S, *Ind Crops Prod*, 140 (2019) 111634.
25 Atassi Y, Said M, Tally M & Kouba L, *Polym Bull*, 77 (2020) 5281.