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RESEARCH ARTICLE

Green Fabrication of Multifunctional Three-Dimensional Superabsorbent Nonwovens with Thermo-Bonding Fibers

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Abstract

Disposable hygiene products have evolved into the important parts for millions of people around the world, enhancing the convenience of daily lives. However, development of the disposable hygiene products is restricted by unsustainable production technology, complicated operation process, and poor liquid absorption performance of the absorbent core. Herein, integrated and three-dimensional (3D) multifunctional superabsorbent nonwovens with liquid-triggered fragrance release was prepared via green, fast and scalable multi effect hot-air anchoring method which physically crosslinking the joint thermo-bonding fibers and anchoring fragrance microcapsules/super absorbent polymer (SAP) onto adjacent thermo-bonding fibers simultaneously. The resulting composite nonwovens could three-dimensionally absorb water 33.14 times of its own weight without gel blockage between SAP, and correspondingly release increased intensity fragrance along with enhancing amount of water absorption. Absorption rate t_1 and t_2 is 83.62% and 50.62% higher than the commercial specimen respectively, and the air permeability is increased by 226.88% compared with the commercial specimen. The superabsorbent nonwovens with controllable fragrance release and odorant synergistic has the potential to be practically applied to functional textiles fields because of the excellent liquid absorption and controlled fragrance release performance, and is easy to be produced on a sustainable, pollution-free and large-scale industrial production.

Keywords 3D superabsorbent nonwovens · Hot-air anchoring · Thermo-bonding fiber · Without gel blockage · Controlled fragrance release · Environmentally friendly

Introduction

With the concept of healthy life gradually lodged itself in the public mind, personal health care [1–6] has captivated much interest because it is vital and imperative in people's daily life. Of particular interest are disposable hygiene products that play an important role in personal health care, including baby diapers [7–9], feminine hygiene products [10–12], and adult incontinence pads [13, 14]. Disposable hygiene products are in huge demand worldwide, but the preparation process of its internal absorbent core does not conform to the concept of environmental friendliness [15–18]. The hot-melt adhesive is needed in the preparation process of the absorbent core, which is polymers that are difficult to degrade after use, and some unpleasant gas will be emitted during the production process. In addition, the composite structure of layer by layer in absorbent core leads to poor liquid absorption performance, which affects people's experience comfort in use.

The absorbent core of disposable hygiene products has experienced the development process from the traditional absorbent core to the nonwoven composite absorbent core. The traditional absorbent core (Fig. 1a) is composed of fluff pulp mixed with SAP, and then covered by a covering material. However, due to the unstable structure of the absorbent core composing of fluff slurry and SAP, the phenomenon of lump and fault will occur in use, which greatly destroys people's sense of comfort. The nonwovens composite absorbent core (Fig. 1b) is composed of dust-free paper or non-woven

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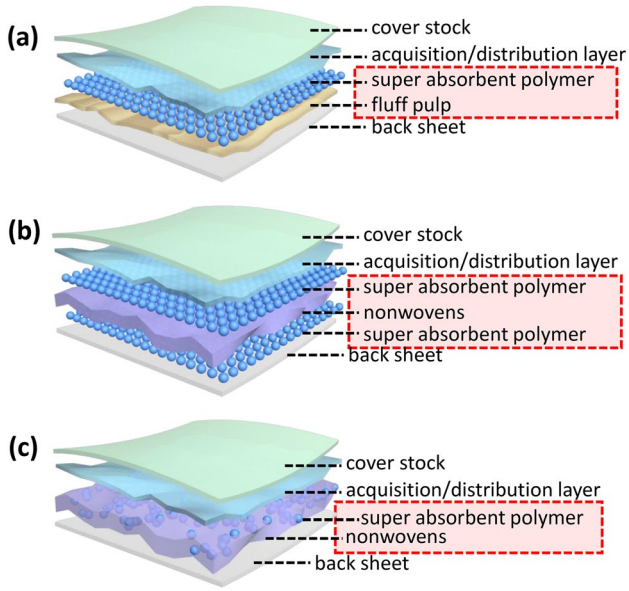

Fig. 1 Disposable hygiene products containing (**a**) traditional absorbent core, (**b**) nonwovens composite absorbent core and (**c**) self-made superabsorbent nonwovens (Inside the dashed box is the part of absorbent core)

fabric, SAP and hot-melt adhesive, which are compacted layer by layer and bonded by hot-melt adhesive. The volume of SAP will expand more than ten times after absorbing water to form gel. However, the gel will block the liquid infiltration channel because the SAP is closely arranged in the absorbent core, resulting in poor absorption and diffusion of urine, and risk of urine leakage.

In addition, in the process of using disposable hygiene products, the odor produced after absorbing excreta, especially adult incontinence pads, is not conducive to the physical and mental health of users. Considering the significance of personal privacy and dignity, disposable hygiene products with deodorization and odor suppression function currently draw more increasing attention globally. Most of these products only utilize physical adsorption to reduce odors by adding such as bamboo charcoal strips, activated carbon or plant-based complex enzymes, which is not able to satisfy the requirements for odor synergy in the process of use.

At present, there are a lot of researches on the preparation of aromatic clothing and textiles by various means [19–24], which mainly focused on the loading or adhering aromatic capsules onto fibers by means of chemical adhesive. Petrulyte et al. [25] loaded the microcapsules containing essential eucalyptus oil onto the ramie/cotton terry fabrics through adhesive to prepare smart aromatherapic textiles. Zhang et al. [26] prepared a double-layered microcapsule with the long-term effectiveness, and loaded it on cotton fabric with binder by the soak-roll method. Ghayempour et al. [27] mixed tragacanth nanocapsules containing chamomile with adhesive, and applied them on the cotton fabric using an UV curing method. Microcapsule technology [28–31] has been widely used in many fields. The microcapsule used to cover essence molecules can effectively prevent the rapid volatilization of fragrance, achieving the effect of controlled fragrance release of aromatic products [32–36]. However, the adhesive contains harmful compounds, such as the formaldehyde, which will cause great harm to human and environment.

Herein, we prepared integrated and 3D superabsorbent nonwovens (Fig. 1c) with liquid-triggered fragrance release function via green, fast and scalable multi effect hot-air anchoring method without additional adhesives. The fluffy structure composed of viscose fibers/ES fibers [37]/hollow polyester fibers make the fragrance microcapsules and SAP uniformly distributed on fiber surface and embedded in the fiber web respectively, which avoids the occurrence of gel blockage compared with traditional absorbent core. Without adding any chemical adhesives, multi effect hot-air anchoring endows fragrance microcapsules/SAP and thermo-bonding fibers quickly form a strong physical bonding inside fiber web as well as cage shrinkage of fiber web. Liquid absorption performance and air permeability of the developed superabsorbent nonwovens have been studied and compared with the commercial specimen. The fragrance microcapsules with the hydroxypropyl-β-cyclodextrin [38, 39] (HP-β-CD) as the wall material could dissolve in water and release fragrance, which achieve the effect of controlled fragrance release and odorant synergistic during use. The superabsorbent nonwovens reported in this paper have good liquid absorption and controlled fragrance release performance, which are easy to be industrialized in large scale, and contribute a practical application potential to the fabrication of functional textiles [40–42].

Experimental Section

Materials

Viscose fibers were obtained from Tangshan Sanyou Group Xingda Chemical Fibre Company. Hollow polyester fibers were provided by Sinopec Yizheng Chemical Fibre Company. ES fibers were supplied by Shandong Derun New Material Technology Company. SAP was obtained from Formosa Plastics Corporation. The microcapsules with lavender essence as the core material and HP-β-CD as the wall material were provided by Shanghai Institute of Technology. Sodium chloride was purchased from HUSHI. Ammonia solution (25–28%) was supplied by Titan. Deionized water was used in all experiments. And all chemicals were used as received without further purification.

Preparation of the Multifunctional 3D Superabsorbent Nonwovens

Viscose fibers, hollow polyester fibers and ES fibers were used as raw materials, which were opened and blended by Opening Machine (BG038-100, China) and Cotton Blender (BG058-120, China), and fed into Double Doffer Messy Carding Machine (BG218A-100, China) to form fluffy fiber web. Then, the microcapsules and SAP are added to the fiber web by mixing and spraying online. After that, the upper and lower layers of the fiber web were compounded and placed in the Hot Air Dryer (GZ-108B, China), and then fixed and shaped by hot-air anchoring.

Test of Liquid Absorption Performance

Absorption Times Test

Weigh the sample with a size of 100 mm × 100 mm as m_1, and completely immerse it in pure water. After 1 min, take it out and hang it vertically for 2 min, and immediately weigh the mass of the sample as m_2. The liquid absorption times Lc is expressed by the ratio of the mass of the liquid absorbed by the sample to the mass of the original sample, as shown in Eq. 1. Each sample was tested 5 times and the average value was taken.

$$Lc = \frac{m_2 - m_1}{m_1} \tag{1}$$

Multiple Absorption Rates Test

Place a 200 mm × 100 mm sample on the test bench with the front side upward. Place a standard dram funnel above the center of the sample and the bottom of the funnel is at a vertical distance of 8 mm from the surface of the sample. Add 30 mL water into the funnel, open the funnel gate to the maximum, and start timing at the same time. Record the time t_1 when the liquid is completely absorbed and stand for 5 min. Repeat the above steps and record the time t_2 when the liquid is completely absorbed again. So t_1 is the first absorption rate, t_2 is the second absorption rate. Each sample was tested 5 times and the average value was taken.

Reinfiltration Amount Test

Weigh the mass of a piece of filter paper as m_3. Place a 200 mm × 100 mm sample on another piece of filter paper with the front side upward. Place a standard dram funnel above the center of the sample and the bottom of the funnel is at a vertical distance of 8 mm from the surface of the sample. Add 30 mL water into the funnel, open the funnel gate to the maximum, and stand for 5 min. Repeat the above steps twice, and put the weighed filter paper on the surface of the sample and then place the standard press block on it when in the 10th minute. Press for 1 min and immediately weigh the mass of the filter paper as m_4. The reinfiltration amount M is expressed by the mass difference of the filter paper before and after the test, as shown in Eq. 2. Each sample was tested 5 times and the average value was taken.

$$M = m_4 - m_3 \tag{2}$$

Subjective Evaluation of Fragrance Release

Add different doses of microcapsules to the superabsorbent nonwovens, pour the same amount of 0.9% sodium chloride solution to it, and let 9 sensory assessors give subjective scores on aroma intensity and aroma comfort. The scores are set from 0 to 10, the higher the score, the stronger the aroma intensity and the better the aroma comfort. The average values of the aroma intensity and aroma comfort were taken.

Characterization

The fiber length was measured by manual tweezers method. The fiber fineness was measured by the mid-section weighing method. The morphologies and microstructures of fibers, microcapsules, SAP and multifunctional 3D superabsorbent nonwovens were observed through Scanning Electron Microscope (DXS-10ACKT, China). The pore size distribution of multifunctional 3D superabsorbent nonwovens was analyzed by Porous Material Pore Size Analyzer (CFP-1100AI, America). The thickness of the multifunctional 3D superabsorbent nonwovens before and after liquid absorption was measured using Fabric Thickness Meter (YG141N, China). The air permeability of the multifunctional 3D superabsorbent nonwovens was investigated using Automatic Air Permeability Tester (YG461E, China). The aroma intensity of the multifunctional 3D superabsorbent nonwovens was performed by gas Ultrafast Gas Chromatographic Electron Nose (Heracles II, France).

Molecular Dynamics Simulation of Polyethylene Heating Process

The Hyperchem software was used to simulate molecular dynamics for the heating process of polyethylene. First, the molecular model of polyethylene with degree of polymerization of 10 was constructed, and then its structure was optimized to find the geometrically optimized structure with the lowest potential energy. After optimization of the polyethylene model, its original size was 2.28 Å × 1.80 Å × 28.18 Å. The periodic box option was adopted and the size of the

periodic box was set to 8 Å × 8 Å × 30 Å. The AMBER force field was used to perform the molecular dynamics simulation of heating process. Heating from the initial temperature of 300 K (28 °C) to the simulated temperature of 408 K (135 °C), the heating time was 20 ps, and the simulation time was 10 ps, The time step was 0.001 ps, and the energy (E) and temperature (T) parameters were collected every 10 time steps.

Results and Discussion

Preparation of the Multifunctional 3D Superabsorbent Nonwovens

The electron micrographs of the fibers used to prepare the multifunctional 3D superabsorbent nonwovens are shown in Fig. 2. It can be seen from the Fig. 2a, e that there are many longitudinal grooves on the surface of viscose fibers, and the cross section is zigzag. It has good hygroscopic property and capillary effect, which can play the role as transport pipeline in the multifunctional 3D superabsorbent nonwovens. The longitudinal surface of the hollow polyester fibers is smooth (Fig. 2b), and the cross section is hollow and nearly circular (Fig. 2f). At the same time, its length is long (Table S1), and the stiffness is strong, resulting in the increase of the fiber surface area per unit volume, which increases the resilience of the prepared multifunctional 3D superabsorbent nonwovens. The resilience of the multifunctional 3D superabsorbent nonwovens is improved, which provides sufficient expansion space for SAP during the liquid absorption process, which reduces the occurrence of gel blockage. The multifunctional 3D superabsorbent nonwovens are less likely to collapse after liquid absorption, which improves its liquid absorption performance.

The ES fibers (thermo-bonding fibers) is sheath-core bicomponent composite fibers. It can be clearly seen from the cross-sectional Fig. 2g, h that the ES fibers are divided into the sheath and the core layer, among which the sheath layer is polyethylene (PE) and the core layer is polypropylene (PP). PE fibers in the sheath layer with low melting point can melt and soften at a certain temperature. After air-flow cooling, the effective bonding point is formed at the cross point of fibers, which provides certain strength for the multifunctional 3D superabsorbent nonwovens. Meanwhile, the effective adhesion is formed at the contact point of the

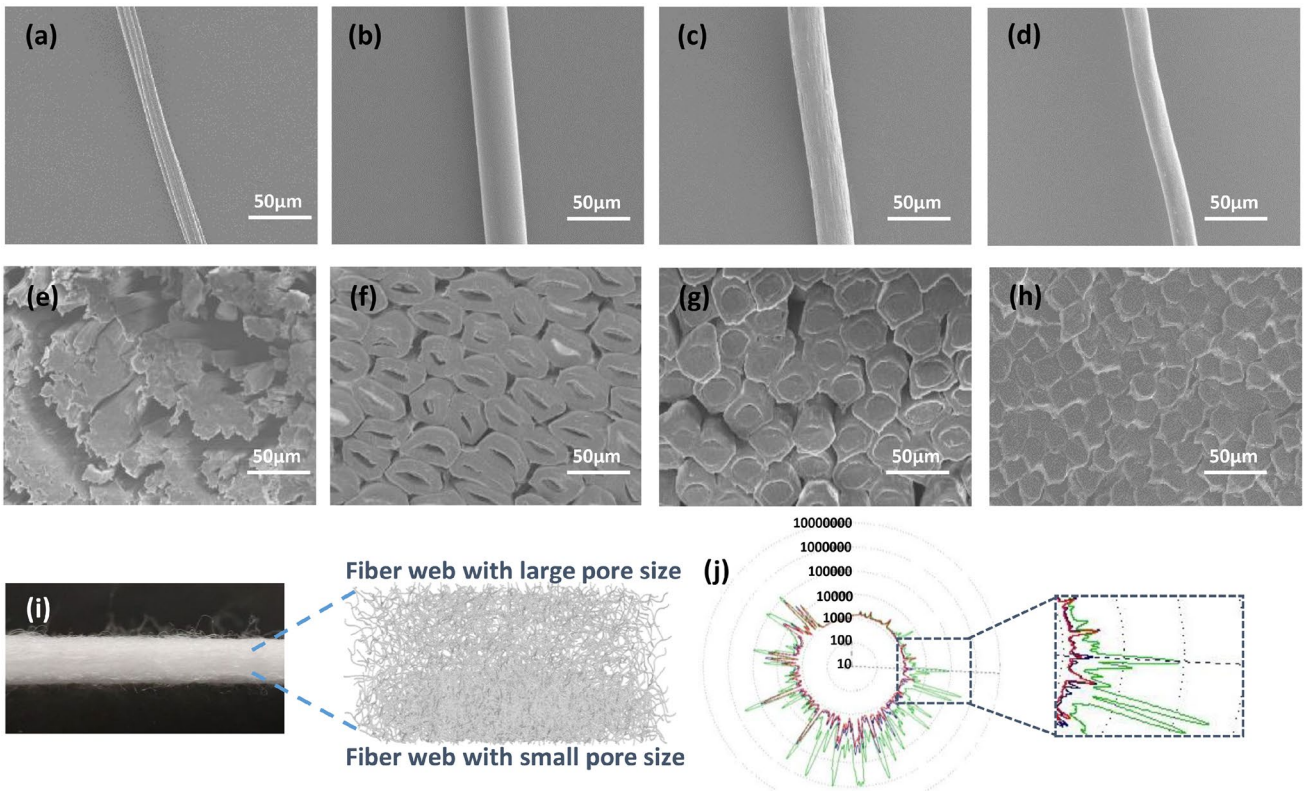

Fig. 2 Surface and cross-sectional electron micrographs of (**a**, **e**) viscose fibers, (**b**, **f**) hollow polyester fibers, (**c**, **g**) upper layer ES fibers, (**d**, **h**) lower layer ES fibers; (**i**) Digital image and schematic diagram of fiber web with gradient structure; (**j**) Aroma intensity radar maps of microcapsules under different treatment conditions (blue line: microcapsules without treatment; red line: microcapsules with heat-treatment; green line: microcapsules in water)

thermo-bonding fibers with SAP/microcapsules, which produces a strong physical bonding. The fiber web with large pores is prepared by the upper layer ES fibers (Fig. 2c) with fineness of 6.67dtex, while the fiber web containing small pores is prepared by the lower layer ES fibers (Fig. 2d) with fineness of 1.8dtex, as shown in Table S1. The pore size of the upper layer fiber web is 78 μm, the pore size of the lower layer fiber web is 55 μm, and the pore size difference on the two surface of the fiber web is 23 μm. ES fibers with different fineness are prepared the multifunctional 3D superabsorbent nonwovens with gradient structure as shown in Fig. 2i, which is conducive to transfer water from top to bottom rapidly.

The SAP used is acrylic resin which can swell after absorbing a large amount of water and keep the water from flowing out. The microcapsules used are micro-particles with HP-β-CD as the wall material and lavender essence as the core material. HP-β-CD introduces hydroxypropyl group into cyclodextrin, which greatly improves the water solubility. It can realize the dissolution and rupture of the wall material when encountering water, so as to achieve the effect of controlled fragrance release. Figure 2j represents aroma intensity radar maps of microcapsules under different treatment conditions. Compared with the untreated microcapsules (blue line), the aroma intensity of microcapsules after heat treatment (135 ℃, 120 s) (red line) has almost no change. Meanwhile, it can be seen from the thermogravimetric curve (Fig. S1) that there is little difference in the weight loss rate of the microcapsules without and after heat treatment at 135 ℃. This indicates that the microcapsule has impressive thermal stability. During the hot-air anchoring process, the wall material HP-β-CD will not be cracked, thus the core material essence will not be lost by volatilization. However, the aroma intensity of the microcapsules encountering water (green line) increased significantly, indicating that the water stability of the microcapsules was poor. It is further proved that the wall material HP-β-CD dissolves and breaks when the microcapsules meet water, thus the core material lavender essence is released, which makes the multifunctional 3D superabsorbent nonwovens can achieve the effect of controlled fragrance release in use.

The amount of microcapsules added directly affects the aroma intensity and comfort experienced by users, so we analyzed it through subjective evaluation. It can be seen from Fig. 3a that adding 15% microcapsules into the multifunctional 3D superabsorbent nonwovens could achieve the optimal aroma comfort for people. Due to the small size and easy agglomeration of microcapsules, the method of mixing with SAP (Fig. 3d) is adopted to sprinkle them into the fiber web, which not only reduces agglomeration between microcapsules, but also makes the microcapsules adsorb on SAP and then enter into the fiber web without falling out. The preparation process of multifunctional 3D superabsorbent nonwovens is shown in Fig. 3e. Firstly, the above-mentioned fibers are mixed uniformly and combed into a fiber web by carding method (Fig. 3f). Then, the microcapsules (Fig. 3b) and SAP (Fig. 3c) are mixed and sprinkled evenly into the fiber web through online spraying (Fig. 3g). Finally, the composite fiber web is fixed and shaped by hot-air anchoring, and the prepared multifunctional 3D superabsorbent nonwovens are shown in Fig. 3h. The multifunctional 3D superabsorbent nonwovens obtained by the above-mentioned continuous preparation process are used for the following preparation optimization and performance testing.

Three core indicators, namely reinfiltration amount, absorption times and multiple absorption rates, were selected to analyze the liquid absorption performance of the multifunctional 3D superabsorbent nonwovens prepared by different process parameters. With the increase of the proportion of hollow polyester fiber, the resilience and bulkiness of the multifunctional 3D superabsorbent nonwovens are improved, which reduces the occurrence of gel blockage, as shown in Fig. S2. Meanwhile, the absorption times of multifunctional 3D superabsorbent nonwovens are reduced and the reinfiltration amount is increased, as shown in Fig. 4a, b. As the weight ratio of the upper layers in the composite structure increases, the reinfiltration amount of the multifunctional 3D superabsorbent nonwovens decreases, as shown in Fig. 4c, d. With the increase of hot-air time and hot-air temperature, the anchoring effect of the fiber web first increases and then decreases, so the liquid absorption performance (Fig. 4e–h) and surface morphology (Fig. S3) of the multifunctional 3D superabsorbent nonwovens also increase first and then decrease. When the hot-air temperature and time are optimal, the fiber melts to form effective adhesion without damaging its original performance properties, thus achieving the best liquid absorption performance. The orthogonal experiment was further designed as shown in Table S2, the optimal process parameters of the multifunctional 3D superabsorbent nonwovens were obtained by comprehensive consideration: fiber ratio of ES fibers: viscose fibers: hollow polyester fibers is 50:44:6, composite structure is 200 + 100 g, hot-air time is 120 s, and hot-air temperature is 135 ℃.

The Mechanism of Multi Effect Hot-air Anchoring

The mechanism of multi effect hot-air anchoring is shown in Fig. 5. In the process of hot-air anchoring, the sheath layer PE with low melting point of the ES fiber melts, and the joints between the thermo-bonding fibers have the effect of bonding. After cooling, the fiber web is fixed and shaped due to the point bonding between thermo-bonding fibers. The multifunctional 3D superabsorbent nonwovens obtained have the advantages of high bulkiness, good elasticity, and soft hand feeling, which can temporarily store liquids more than 10 times of its own mass, endowing it excellent liquid

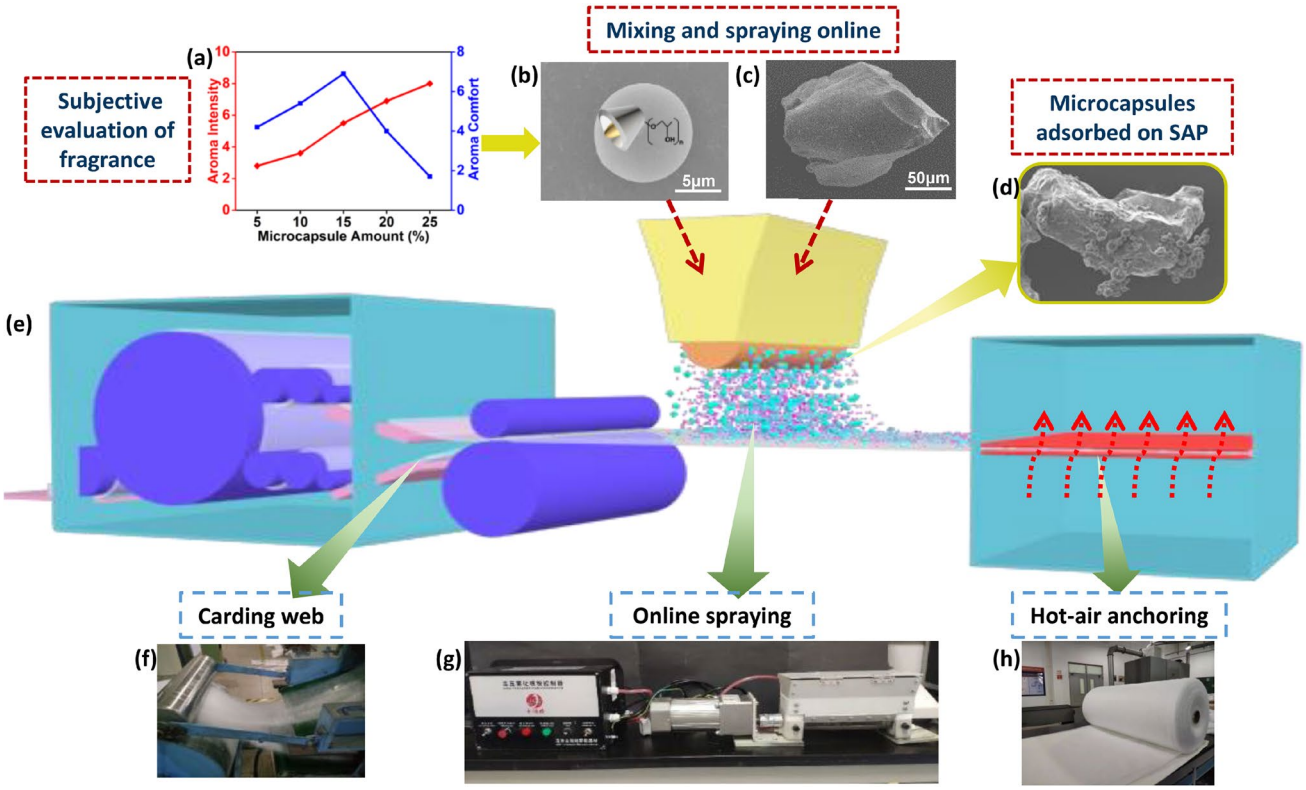

Fig. 3 **a** The subjective evaluation of microcapsules amount (based on weight of nonwovens) on aroma intensity and aroma comfort; **b** Electron microscope image and molecular structure diagram of microcapsules; **c** Electron micrograph of SAP; **d** Electron micro graph of microcapsules adsorbed on SAP; **e** Schematic diagram of preparation process for multifunctional 3D superabsorbent nonwovens; Digital images of **f** carding web, **g** online spraying and **h** the multifunctional 3D superabsorbent nonwovens prepared by hot-air anchoring

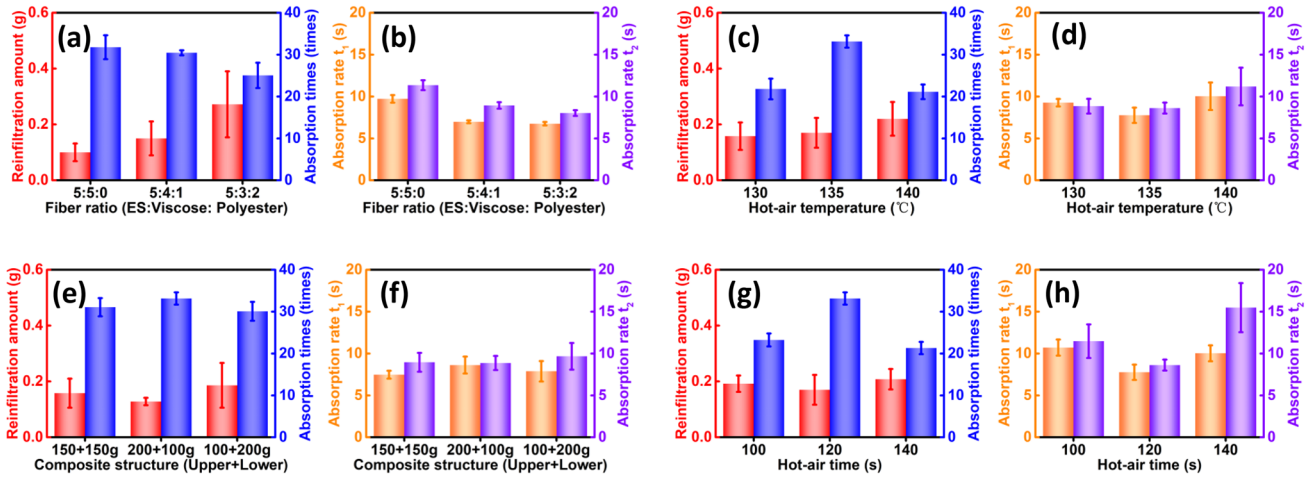

Fig. 4 Influences of fiber ratio (**a**, **b**), composite structure of fiber web (**c**, **d**), hot-air time (**e**, **f**) and hot-air temperature (**g**, **h**) on liquid absorption performance (reinfiltration amount, absorption times and multiple absorption rates (t_1, t_2)) of the superabsorbent nonwovens

absorption performance. Due to the cage shrinkage of the fiber web caused by the hot-air anchoring, the SAP is embedded in the fiber web to form a firm physical combination. The average pore size of the fiber web before hot-air anchoring is larger, so the SAP in the fall movement could enter the inside of the fiber web smoothly probably due to scalability

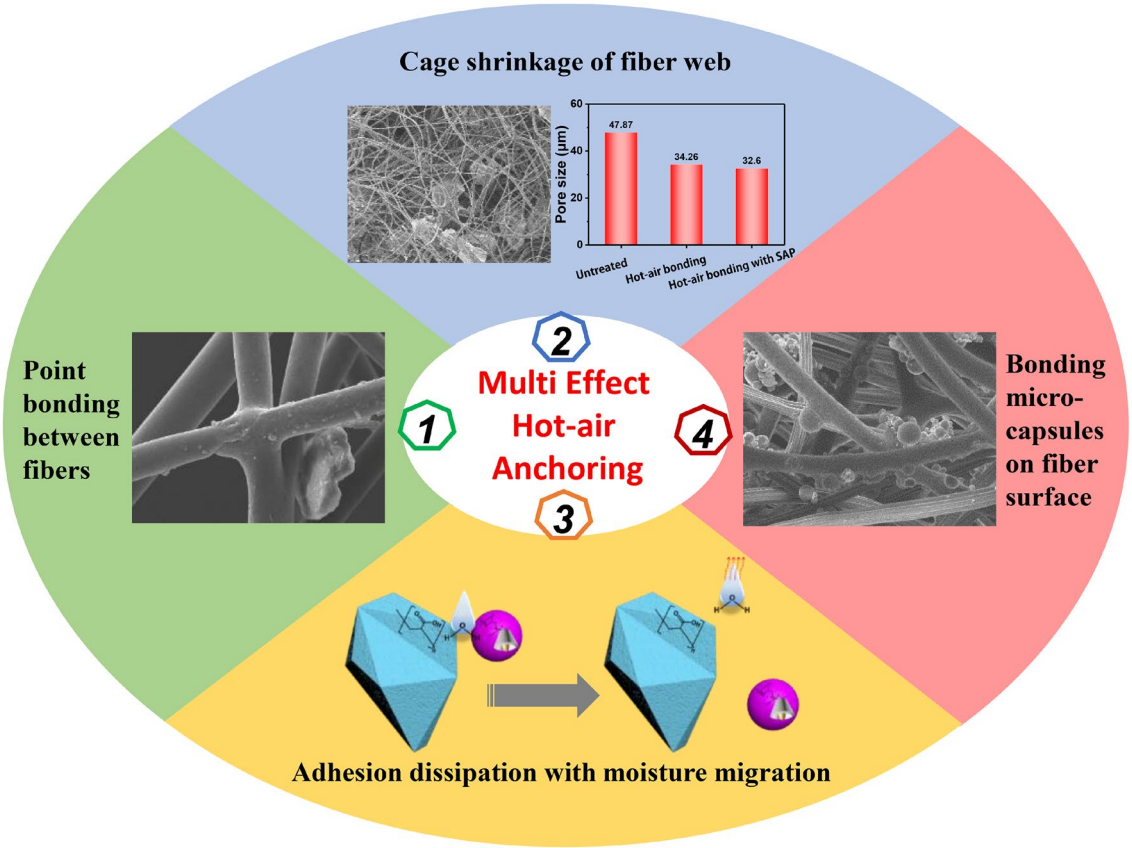

Fig. 5 Schematic diagram of multi effect hot-air anchoring mechanism: (1) Electron micrograph of thermo-bonding fiber point bonding; (2) Electron micrograph of SAP distribution; the average pore size distribution of fiber web with untreated, hot-air anchored and hot-air anchored with SAP; (3) Schematic diagram of the combination mechanism between SAP (blue particle), microcapsules (purple ball) and moisture (transparent droplet); (4) Electron micrograph of microcapsules distribution on thermo-bonding fiber surface

of fiber web. The average pore size after hot-air anchoring becomes smaller, so that the SAP which is previously scattered into the fiber web is tightly entangled among the fibers, and embedded in the fiber web cannot move, thus forming a firm physical interception.

The PE component of the ES fiber is thermoplastic. When it reaches a certain temperature, it will soften and melt, becoming a viscous fluid with fluidity, and then re-solidify after cooling. The hot-air anchoring process is to make use of this characteristic to soften and melt PE fibers after heating, resulting in adhesion between the thermo-bonding fibers, and anchoring SAP and microcapsules with thermo-bonding fibers. At room temperature, polyethylene is in glassy state, the molecular chain segments are in frozen state, the molecules are arranged regularly, as shown in Fig. 6a, and the macro-state is shown in Fig. 6c. During the hot-air anchoring process, as the temperature increases, the polyethylene molecules absorb heat, the atomic bond length elongates, the bond angle and the dihedral angle between atoms change, the whole molecular chain bends, as shown in Fig. 6b, and the macro-state is shown in Fig. 6d. When the polyethylene is heated to 135 °C (that is the PE's melting temperature), the polyethylene is in viscous fluid state, the whole molecular chain slips with each other, and viscous flow occurs, which makes the adhesion of PE fibers with SAP and microcapsules, achieving the anchoring effect after cooling. The change law of temperature and potential energy in the heating process of PE is shown in Fig. 6e, f. The changing trend of temperature and total energy (including kinetic energy and potential energy) in the whole system increases with heat time.

The schematic diagram of the combination mechanism between SAP and microcapsules is shown in Fig. 7a. As the wall material HP-β-CD of the microcapsules contains many hydroxyl groups, it is easy to form hydrogen bonds with moisture molecules, so the agglomeration is very easy to occur when exposed to air (Fig. 7b), which is not conducive to the uniform dispersion of the microcapsules in the fiber web. SAP, as a super absorbent material, has high amount of hydrophilic groups on its surface, such as – COOH, which makes it easier to absorb moisture. After mixing SAP with the microcapsules, – COOH on SAP is

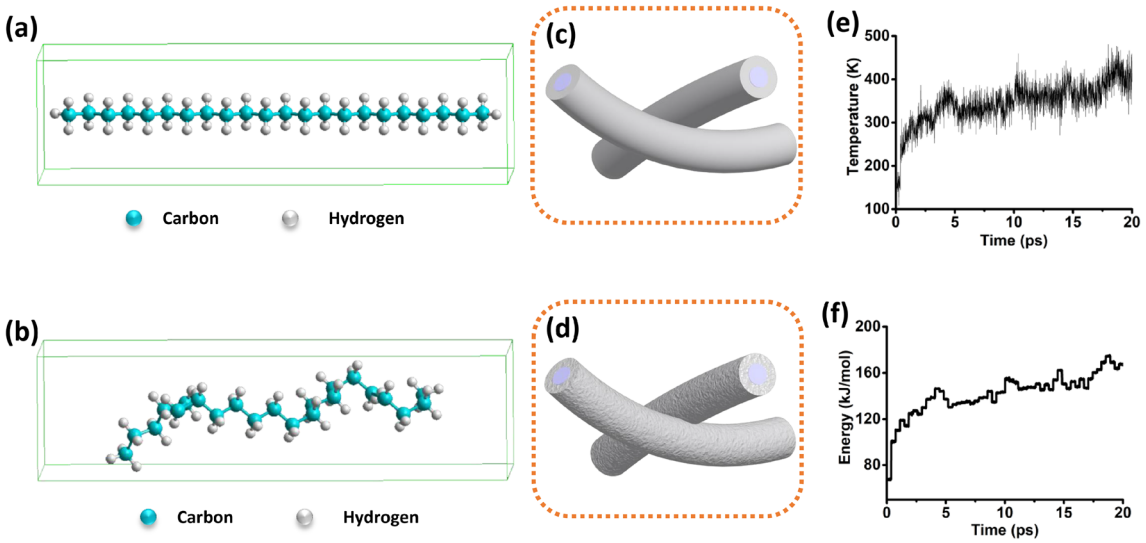

Fig. 6 Molecular model diagram and schematic diagram of polyethylene in (**a**, **c**) room temperature and (**b**, **d**) high temperature; The change of (**e**) temperature and (**f**) total energy with time in the heating process of polyethylene model

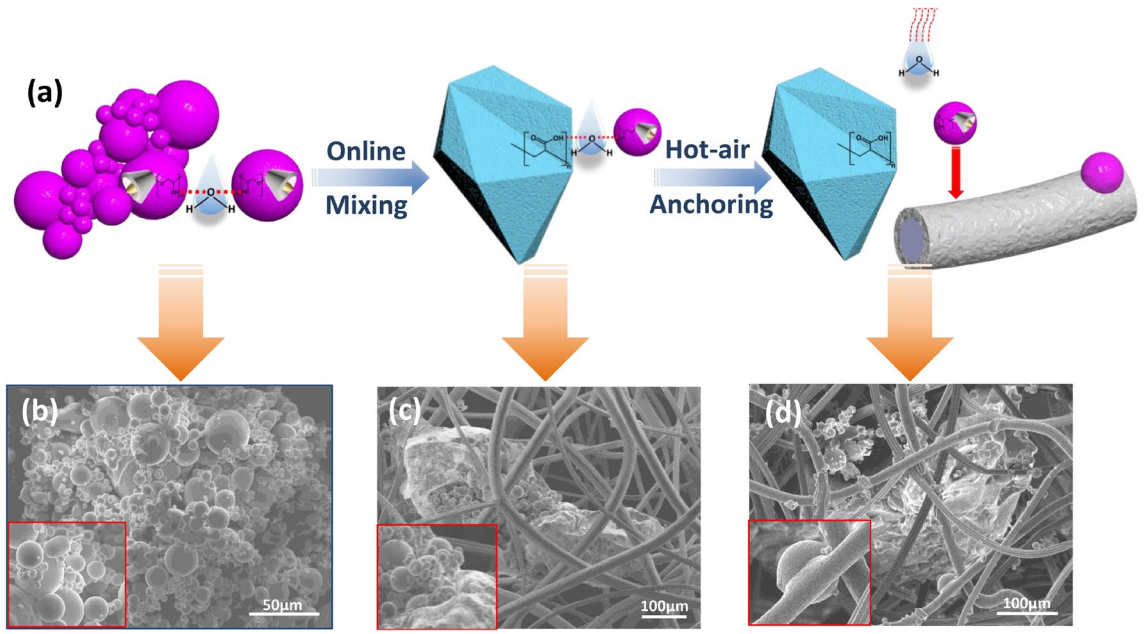

Fig. 7 **a** Schematic diagram of the combination mechanism between SAP and microcapsules; Electron microscope images of **b** self-agglomerated microcapsules; Electron microscope images of the distribution of microcapsules and SAP in the fiber web after **c** online mixing and **d** hot-air anchoring

more likely to form hydrogen bonds with -OH of moisture, and the moisture molecules that make the microcapsules agglomerate could be snatched away to some extent, so that the microcapsules and SAP could be connected together through hydrogen bonds of moisture molecules, as shown in Fig. 3d. The hydrogen bond between them enables the microcapsules to be dispersed and adsorbed on the surface of SAP, reducing their own agglomeration and being brought into the fiber web together (Fig. 7c).

In the process of multi effect hot-air anchoring, due to the influence of high temperature, all the molecules move violently and moisture evaporates quickly. As a result, water molecules between microcapsules and SAP disappear with evaporation, so part of the binding force between them

disappears. The microcapsules that lose the binding force fall on the surface of adjacent PE fibers, and then the molten PE fibers anchor them firmly. Due to the high thermal stability of the microcapsules, the essence in the microcapsules core will not be abruptly volatilized. As shown in video 1, 2, the multifunctional 3D superabsorbent nonwovens bonded by multi effect hot-air anchoring will not drop out the microcapsules under bending (Fig. S4a, b) and blowing (Fig. S4c, d), indicating that the microcapsules have been firmly bonded without any additional adhesives.

Performance of the Multifunctional 3D Superabsorbent Nonwovens

The absorbent cores of two kinds of disposable hygiene products in foreign (specimen1) and domestic (specimen2) are selected to compare their liquid absorption and air permeability performance with that of the developed multifunctional 3D superabsorbent nonwovens in this research. It can be seen from Table 1 that compared with the specimen 2, the absorption times of multifunctional 3D superabsorbent nonwovens in this work is higher, and the reinfiltration amount is also larger. The SAP and fluff pulp in specimen 2 with large weight are mostly distributed in the surface layer, resulting in water can only be stored on the surface layer and cannot penetrate to inside. The SAP in the self-made multifunctional 3D superabsorbent nonwovens, however, is evenly dispersed in 3D porosity of the nonwovens, and the water could diffuse and penetrate inside rapidly, leading to high liquid absorption amount (16.48 times) based on the sample weight before liquid absorption and relatively high reinfiltration.

Interestingly, compared with two kinds of absorbent cores in commercial, the multiple absorption rates of the self-made multifunctional 3D superabsorbent nonwovens are greatly improved. The absorption rate t_1, t_2 of self-made multifunctional 3D superabsorbent nonwovens are 42.50%, 9.90% higher than that of specimen1, and 83.62%, 50.62% higher than specimen 2 respectively. This is due to the fact that the SAP of the specimen 1 and 2 are mainly distributed on the surface layer of the absorbent core, and swells after absorbing water to cause the phenomenon of gel blockage, as shown in Fig. S5d, e. As a result, the liquid remains on the surface of the absorbent core and hardly infiltrate into the sorbent interior, leading to comparatively lower absorption rates, including t_1 and t_2 for both of specimen 1 and specimen 2. Analyzing in terms of micro structure between SAP and fibers in nonwovens, SAP in the self-made multifunctional 3D superabsorbent nonwovens is evenly dispersed among intercommunication pores formed between fibers in 3D nonwovens, as shown in Fig. 1c. Resultantly, even if the SAP in the self-made multifunctional 3D superabsorbent swells with water, gel blockage would not easily occur, as shown in Fig. S5f, which greatly improves the liquid absorption performance properties.

The thickness of the self-made multifunctional 3D superabsorbent nonwovens is the smallest before and after absorbing water, as shown in Fig. S6, especially the thickness difference before and after liquid absorption of which is about twice as small as that of specimens1 and 2. In addition, the air permeability of the self-made multifunctional 3D superabsorbent nonwovens is much higher than that of the other two specimens, 226.88% higher than specimen1 and 51.33% higher than specimen2, as shown in Fig. S6. All these results are caused by the SAP in the self-made multifunctional 3D superabsorbent nonwovens being designed uniformly dispersing in the 3D porous nonwoven structure, as shown in Fig. 1c. The thinner and more breathable absorption materials are conducive to people's experience of comfort during use.

In the process of use, a large amount of water disperses the wall materials of aromatic microcapsules, and the fragrance is easier to volatilize and release. As the amount of water added is on the rise, the aroma intensity released gradually increases, as shown in Fig. 8a–c and radar maps Fig. 8d. The height of the peak in the radar maps represents the intensity of the aroma, the higher the peak, the stronger the aroma intensity. Dilute ammonia solution 1000 time with water as simulated urine. According to the proportion of 300 mL adult urine at one time, pour the simulated urine into the multifunctional 3D superabsorbent nonwovens with 15 wt% microcapsules (based on weight of nonwovens). It is worth mentioning that the odor of the simulated urine is offset, weakened and masked, as shown in Fig. 8e, due to the interaction between the odor molecules of urine and the essence molecules released by the microcapsules, which indicates that the prepared multifunctional 3D superabsorbent nonwovens have the effects of odorant synergistic.

Table 1 Liquid absorption performance of three types of specimens

Test samples	Weight/g	Absorption times/times	Absorption rate t_1/s	Absorption rate t_2/s	Reinfiltration amount/g
Specimen1 (foreign)	16.59	17.93	12.44	9.77	3.07
Specimen2 (domestic)	19.05	12.32	16.03	13.39	1.76
This work (self-made)	12.82	16.48	8.73	8.89	3.44

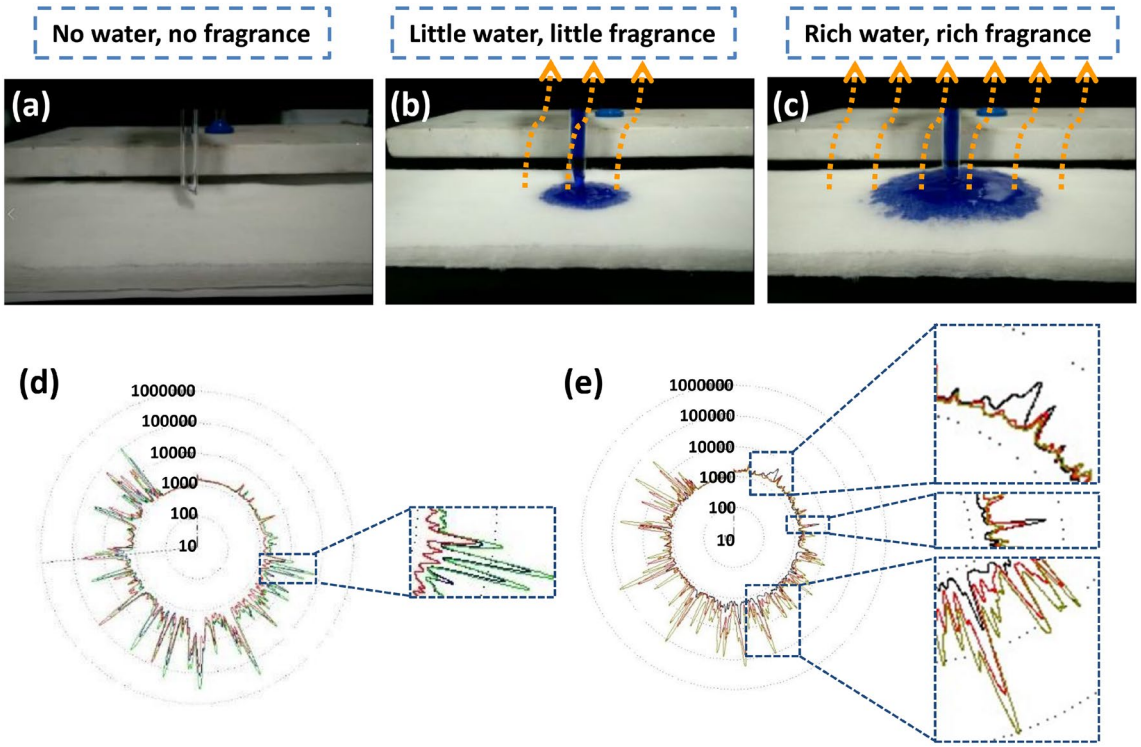

Fig. 8 **a**–**c** Schematic diagrams of the aroma intensity of the multifunctional 3D superabsorbent nonwovens with the increase of added water; **d** Aroma intensity radar maps of the multifunctional 3D superabsorbent nonwovens after adding different amounts of water (red line: no water; blue line: littler water; green line: rich water); **e** Aroma intensity radar maps of simulated urine (blue line), multifunctional 3D superabsorbent nonwovens in urine (red line) and microcapsules in water (orange line)

Conclusions

In summary, an integrated, environmentally friendly and controlled fragrance release multifunctional 3D superabsorbent nonwovens have been prepared by carding web, online spraying and multi effect hot-air anchoring. In particular, the multi effect hot-air anchoring produces point bonding between thermo-bonding fibers to shape the fiber web, while the fiber web exhibits cage-like shrinkage so that the SAP is firmly embedded inside. At high temperature, polyethylene molecules absorb heat to form viscous fluid, the adhesive force between SAP and microcapsule disappears, and the adhesion of polyethylene with SAP and microcapsule occurs, forming a green and strong anchoring effect after cooling. SAP is uniformly distributed in the fluffy multifunctional 3D superabsorbent nonwovens, so that it can absorb water 33.14 times of its own weight without gel blocking. The absorption rate t_1 and t_2 are 83.62% and 50.62% higher than the commercial specimen, and the air permeability is 226.88% higher than the commercial specimen. During usage, the aroma intensity released increases as the amount of water added increases, and it has the effect of offsetting, weakening and masking the urine odor molecules. Compared with the absorbent core of traditional disposable hygiene products, the integrated self-made absorbent core prepared without any hot-melt adhesive has the effect of good liquid absorption, controllable fragrance release, as well as the odorant synergistic, which provides valuable application prospects for functional textiles, and potentially contributes to healthcare industry.

Appendix A. Supplementary data

Supplementary data related to this article can be found at.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42765-021-00108-5.

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Declarations

Conflicts of interest The authors declare no competing financial interest.

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