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Development of hybrid cotton/hydrogel yarns with improved absorption properties for biomedical applications

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ABSTRACT

Hyperhidrosis, or excessive sweating, is an overlooked and potentially disabling symptom, which is often seen in social anxiety disorder. In this work an innovative advanced textile material was developed for application in the management of excessive sweating, preparing a drying yarn providing improved comfort. Hybrid cotton/hydrogel yarns were obtained by combining cotton with superabsorbent hydrogels through an optimization study focused on the achievement of the most promising product in terms of absorption properties and resistance to washings. Swelling and washing tests were performed using different hydrogels, and the effect of an additional crosslinking on the materials was also evaluated by testing different solutions containing Al^{3+} and Ca^{2+} ions. Scanning electron microscopy and infrared spectroscopy analyses were adopted to characterize morphology and chemical structure of the hydrogels undergoing different production processes. The biocompatibility of the hybrid fabrics was demonstrated by 3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyltetrazolium bromide colorimetric assay (MTT) through the extract method.

1. Introduction

Hyperhidrosis (HH), or excessive sweating, is an overlooked and potentially disabling symptom, which is often seen in social anxiety disorder (SAD) [1]. Hyperhidrosis can have a deeply detrimental effect on the quality of the life, resulting in dramatic impairments of daily activities, social interactions and occupational activities [2]. It adversely affects one's ability to perform in workplaces, be in public, meet people, and develop personal relationships. Many patients must change their clothing several times per day [3]. Hyperhidrosis can lead to embarrassment, frustration, social withdrawal, low self-esteem, and even medical illness [4]. The sweating cognitions were demonstrated strongly related to sweating severity, and also to social anxiety and anxiety sensitivity [5].

HH can be generalized, involving the whole body, or focal, involving a limited body area most often the feet, armpits, hands or face [2]. Primary or essential hyperhidrosis must be strictly differentiated from secondary hyperhidrosis, which is due to a variety of stimuli, such as infection, malignancy, medication, anxiety, neurological and endocrine disorders [6]. A study provided evidence that severe primary hyperhidrosis is most frequently a hereditary disorder [7]. The condition of HH is believed to be caused by hypothalamic over-activity, transmitted to the hands, feet and face by the sympathetic nervous system. Application of topical agents containing aluminium hydroxide, administration of medications and iontophoresis have been adopted on patients affected by HH, but their usefulness is limited, especially in patients with severe symptoms [8]. The management of HH is typically divided into nonsurgical and surgical approaches [9]. Botulinum toxin A injections have become a common practice in a dermatologist's office for cosmetic applications and hyperhidrosis [10]. Oxybutynin, not approved for hyperhidrosis, has been demonstrated to be a very effective and simple treatment with only mild side effects [11]. Suction curettage is an effective surgical therapy option that can largely reverse the disabilities experienced by patients with excessive axillary sweating [12]. Understanding why patients have excessive sweating of the hands and feet begins with understanding the complex interaction between thermoregulatory sweating and emotional sweating [13,14]. Thermoregulatory sweating is the major mechanism of heat dissipation by whole-body eccrine glands, is controlled by the hypothalamus, and is diurnal or nocturnal [14]. Thermal comfort in human body, which is influenced by both body temperature and sweating from human skins, is greatly affected by heat and moisture transfer from sweating skins to ambient through clothing [15]. The presence of a dry layer next to the skin improves the comfort of clothing [16]. Moisture flow through textile materials is important in many ranges of textile applications including casual wear, sportswear, textile processing and cleaning [17]. The main task of clothing is temperature regulation for the body and thus relief of the circulatory organs, maintaining body and mental performance and imparting a sense of comfort, even under the least favourable climatic conditions [18]. The thermal comfort of a garment depends on several factors: heat and vapour transport, sweat absorption and drying ability. For wearer comfort, sweat should be transported away from the

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Table 1
Physical properties for superabsorbent fiber.

Colour	Oasis 102/52/10	Oasis 122/52/10
	White	White
Staple length (mm)	50 ± 2	48 ± 2
Moisture content (%)	13.5–16%	13.5–16%
Count (dtex)	10 ± 1	10 ± 1
Soluble polymer (%)	≤10	≤3.5
pH (saline extract)	5.5 ± 0.5	5.5 ± 0.5

Table 2
Absorbency properties for Oasis superabsorbent fibres.

	Absorbency [g/g]	
	Oasis 102/52/10	Oasis 122/52/10
15 minute free swell capacity (0.9% saline)	48	30
Free-swell capacity	>140	>80
0.5 psi retention capacity (0.9% saline)	38	20
0.3 psi absorption under load	45	45

skin surface, in the form of liquid or vapour, so that the fabric touching the skin is felt dry. Natural fibres such as cotton are hydrophilic, meaning that their surface has bonding sites for water molecules [19].

The main component of natural fibres is cellulose, which has a complex composite structure organized in elementary fibrils arranged in micro-, macro-fibrils and fibril bundles. The semicrystalline form of cellulose, consisting of both highly crystalline and amorphous regions, influences the sorption properties of the fibres [20,21]. Indeed, bulk water sorption in cotton is limited by the high crystallinity of cellulose and water can penetrate only in the amorphous parts. An increased water sorption, associated with a strong drying effect, could be achieved if super-absorbent hydrogel fibres would be added to a cotton yarn.

Hydrogels are an interesting class of materials characterized by the capability of absorbing extremely large amounts of water, up to 5 L/g. Hydrogels are obtained by chemical or physical stabilization of macromolecular chains in a 3D polymeric network [22] and can be adopted in many application fields. Particularly, hydrogels are appealing materials for application in wound dressings, because they can provide the wound with a moist environment and can also serve as matrix for the delivery of biomolecules and antimicrobial agents [23]. An example of the combination of hydrogel and textiles is the photopolymerization synthesis of a hydrogel containing ZnO nanoparticles synthesized on cotton fabrics [24]; cotton fabrics have been also coated with fumaric acid crosslinked carboxymethylcellulose hydrogel based silver nanocomposites with antibacterial properties [25]; thermal-sensitive hydrogels grafted onto textile substrates have been adopted for thermal-sensitive controlled release properties as a response to human skin temperature in wound dressing and skin care products [26]. In this work superabsorbent hydrogels have been incorporated into textiles to improve the absorption properties of the material and, hence, to reduce the contact between sweat and skin and the related discomfort. The product developed is extremely innovative and nothing similar is available on the market today. It has been designed to provide patients affected by hyperhidrosis with improved comfort; however its use can be enlarged to many biomedical applications such as hospital gowns, sheets, wound dressings etc., for improved absorption of sweat, exudate and biological fluids.

Different parameters, such as the type of the hydrogel and the effect of additional crosslinking, were tested with respect to the swelling degree and the durability to washings, in order to obtain a product reproducible on large scale.

2. Materials and methods

A superabsorbent material was chosen, in order to achieve the best cotton-hydrogel system regarding their sweat absorption and durability to washings. Hydrogels “Oasis 102/52/10” and “Oasis 122/52/10” based polymers of acrylic acid were provided from Technical Absorbent, UK. The numbers 102 and 122 refer to the product code and indicate respectively a standard product for carded non-woven/yarns with good absorbency properties and a high wet integrity product with increased wet mechanical strength. The number 52 indicates the length of the fibres in mm; the number 10 refers to the count in dtex. The physical properties of the hydrogels are reported in Table 1.

An Italian textile company (Megatex, Lecce, Italy) provided raw cotton for this study. Random short fibres of each hydrogel were dispersed into raw cotton (20 wt% hydrogel–80 wt% cotton); then, two different blended yarns were produced by using Oasis 102/52/10 and Oasis 122/52/10 respectively. The spinning process was conducted at 21 °C and 20% humidity, in order to avoid humidity absorption during the manufacturing process. The yarns containing the different hydrogels were adopted to produce two classes of fabrics. They were characterized with respect to the absorption properties and resistance to washings.

The protocol for the evaluation of the absorption properties provided the immersion of samples in saline solution (1 l) for 10 min, the removal of excess solution for 5 min and the calculation of the free swelling degree through the following equation:

$$\text{swelling degree} = \frac{\text{weight swollen sample} - \text{weight dry sample}}{\text{weight dry sample}} * 100.$$

Before testing, all the samples of fabrics were dried in oven for 12 h at 40 °C. A saline solution (0.95% of NaCl by weight) was adopted to simulate the sweat. The swelling degree was calculated before and after industrial washing cycles at 40 °C for 30 min by using an Electrolux washing machine model W4180H with the use of a softening agent (Morbisol Eco from Anco Ltd).

Once defined the best cotton-hydrogel system from the previous characterization, the hydrogel fibres and the cotton-hydrogel yarn were characterized by scanning electron microscopy SEM (ZEISS EVO)

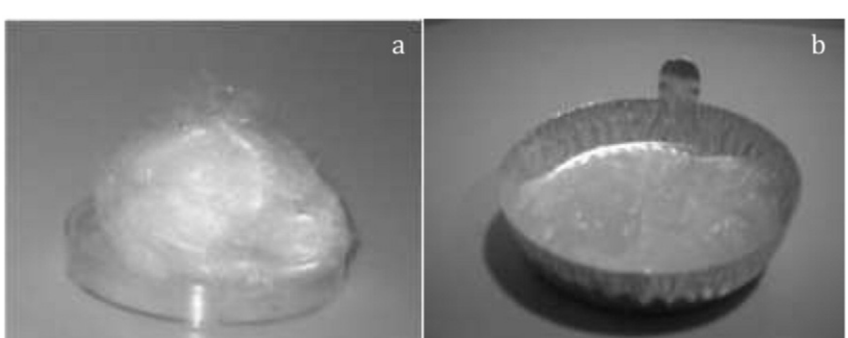

Fig. 1. Pictures of the hydrogel fibres Oasis 122/52/10 before (a) and after (b) the absorption of water.