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Сравнительный анализ носков, изготовленных по инновационной технологии из специальных синтетических волокон

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Аннотация. Функциональный текстиль охватывает широкий спектр различных материалов и продуктов. Понятие «функциональность» относится к свойствам, которые обычно не достигаются с помощью обычного текстиля. Функциональным свойством может быть огнестойкость, антистатичность или антимикробное действие. Добавление таких функциональных свойств часто требуется для самых разных типов одежды. Объектом исследований в данной работе были выбраны функциональные носки как коммерческий продукт. Особое внимание в работе уделено составу волокон этих носков и теплоизоляции продукта. Для этого рассмотрены шесть различных носков, доступных потребителю, которые, как заявляет производитель, обладают определенными функциональными свойствами. Для сравнения был исследован эталонный вариант – носок без специально заявленных функциональных свойств. Все носки содержат по крайней мере один из видов традиционного сырья, например, полиэфирные, полиамидные или хлопковые волокна. Пять носков содержат эластан в количестве от 2 % до 6 %, чтобы улучшить посадку изделий. Заявленные функциональные свойства достигаются за счет содержания инновационных волокон в этих трикотажных изделиях. Модакриловые хлорсодержащие волокна используются для достижения огнестойких свойств. Использование электропроводящих волокон, например, углеродных волокон, формирует антистатические свойства. Только для одного продукта упоминается применение биоцида для реализации эффекта защиты против насекомых. Носки исследовались с помощью сканирующей электронной микроскопии (СЭМ) и испытательной установки для определения теплоизоляционных свойств с использованием тепловой камеры, измеряющей температуру поверхности. Теплоизоляционные свойства носков можно четко определить. Однако интенсивность изоляции сильно зависит от типа продукта и области измерения – подушечки стопы, подъема или пятки. В результате установлено, что для создания функциональных носков используется широкий спектр различных материалов. Исследованные носки являются прекрасными примерами текстильных функциональных изделий, выполненных с использованием специальных видов синтетических волокон.

Ключевые слова: носки, функциональный текстиль, функциональные волокна, теплоизоляция.

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Comparative analysis of innovative socks made from special synthetic fibers

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Abstract. Functional textiles cover a broad range of different materials and products. The term of functionality is related to properties which are typically not reached with conventional textiles. A functional property can be flame retardancy, antistatic or antimicrobial action. The addition of such functional properties is often demanded for very different types of clothes. To focus this actual report, an overview on functional socks as commercial products is given. A special view is made on the fiber composition of these socks and the thermal insulation of the product. For this, six different commercially available socks are considered which are all claimed to certain functional properties. Also, a reference material – sock without especially claimed functional property – is discussed. All socks contain at least one of the conventional fibers as polyester, polyamide and cotton. Five socks contain elastane in an amount of 2 % to 6 %, to improve the fit of the products. Claimed functional properties are achieved by a content of high-performance fibers in these knitted products. Modacrylic fibers with chlorinated co-unit are used to achieve flame-retardant properties. The use of conductive fibers, as e.g. carbon fibers, leads to antistatic properties. Only for one product a biocide application is mentioned for realization of an anti-insect effect. The socks are investigated by using scanning electron microscopy (SEM) and a test set-up for determining the thermal insulation properties by using a heat camera measuring the surface temperature. The thermal insulation properties of the socks can be clearly determined. However, the intensity of insulation strongly depends on the type of product and the area of measurement – foot ball, instep or heel. Finally, it can be stated that a broad range of different materials are used to create functional socks. For this, socks are excellent examples for textile functional products realized with special synthetic fibers.

Keywords: socks, functional textiles, high-performance fibers, thermal isolation.

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Introduction

The functionalization of textiles refers to their aimed functional modification with additional or improved properties with regard to a specific application. A distinction can be made between the fiber-specific, physical properties and the, mostly superficial added properties, which are mainly realized by finishing processes. Functional fiber-specific properties can be realized by addition of high-performance fibers (Mahltig & Grethe, 2022). Prominent examples for high-performance fibers are Kevlar (para-aramid) for cut-resistance and flame-retardancy or modacrylic with chlorinated co-units (Kanecaron) for flame-retardancy (Mahltig & Grethe, 2022; Mahltig, 2021). Please, compare the totally different chemical structures of both high-performances fiber in Figure 1. Examples for functionalization by finishing processes are the application of flame-retardant agent or antimicrobial substances (Lam, Kan & Yuen, 2012). Functionalized textiles are particularly popular in the outdoor clothing sector (Miao, Wang, Yu & Ding, 2022). Outdoor clothing generated sales in Germany in 2023 of around 270 million Euro. Till 2029 a growth of nearly 35 million Euro to finally around 315 million Euro is forecasted in this section (Statista, 2024a). Important clothing categories in terms of functional textiles are: Sportswear and workwear. The latter in particular has the intention to protect humans from external influences. Frequently aimed are functional properties as e.g. breathability, wind and waterproof but also flame retardancy (Cheng et al., 2020). Due to the broad range of different functional textile products available on the market, the actual report has to focus on a special type of cloth. This focus is set to socks, where products with manifold functional properties are offered on the market. A special view is made on the fiber composition of these socks and their thermal insulation properties. Even if the size of a sock is small comparable to other pieces of clothes, they are economically important products. The German market for socks has achieved around 1.6 billion Euro in 2023. The trend of the markets is positive. There is an increasing demand for socks in Germany forecasted till 2028 (Statista, 2024b).

For the current overview, six different commercially available socks are considered which are all claimed to certain functional properties. Also, a reference material – sock without especially claimed functional property – is discussed. One aim of the current study is to report on the broad variation of functional properties and materials which are commercially available with textile socks. A special view is done on the used fiber materials and high-performance fibers. For evaluation of thermal insulation properties, a simple test is developed which is set in simple relation to consumer application and the textile sock as special product. The description of the testing procedure by using a heat camera can be as well used to transfer this test set-up for evaluation of other types of clothes and is by this of general interest for people, who are working in the field of functional textiles and clothing products.

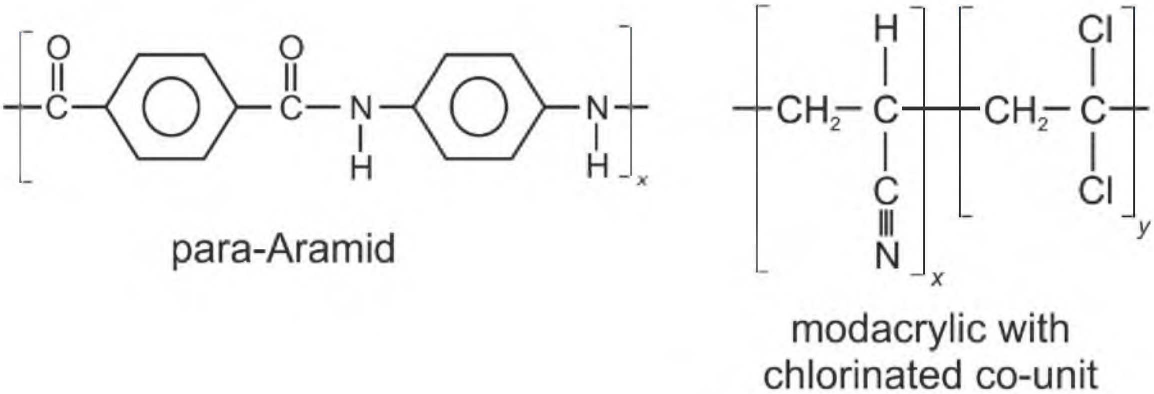

Figure 1 – Chemical structures of polymers related to high-performance fibers – left: para-Aramid; right: acrylic with chlorinated co-unit for flame-retardant properties

Table 1 – Overview on discussed functional socks, presented are trade names, suppliers and labels & standard mentioned by the supplier. Trade names originally in German language are also given in the English translation. The sample sock R is a reference material without special promotion as functional textile material

No.	Name	Supplier	Mentioned Labels & Standards
R	Herren Vollfrotteesocken "Men's full terry socks"	Ronly	Oeko Tex Standard 100
1	Flammschutz Arbeitssocken "2505" schwarz "Flame retardant work socks "2505" black"	Blaklader Workwear	EN 1149; EN 14116
2	Tech Summer Socks	Diadora Utility	ISO 9001:2015
3	ESD Funktionssocke-Sommer Schwarz/Grau "ESD functional socks summer black/gray"	Runnex	CE-Label
4	SK24 Bamboo Hiker Socks	Portwest	Not mentioned
5	BHP001 Thermoactive Workwear Socks	Brubeck Protect	Not mentioned
6	Top Flame Long	Cofra	EN 11612A1B1C1:2008, EN1149-5:2008

Materials and Products

For the current overview on commercially available textile socks, seven different products are considered (Table 1). Six products are distributed by the suppliers with claimed functionals properties. These products are named as sample 1 to 6. As reference material, conventional sock is chosen, which is sold for clothing purposes without claiming further functional properties. This product is named as sample R and is the only one in this selection carrying an Oeko Tex Label (Table 1). For the two samples 1 and 6 dedicated to flame retardant properties, standards related to flame retardancy and antistatic properties are given.

An overview on functional properties and the containing fiber materials as given as supplier information is listed in Table 2. All socks contain at least one of the conventional fibers as polyester, polyamide and cotton. Five socks contain elastane in an amount of 2 % to 6 %, to improve the fit of the products. Also, for the reference sample properties as "warming" and "high wearing comfort" are mentioned. Claimed functional properties are achieved by a significant content of high-performance fibers in

Table 2 – Overview on discussed functional socks, presented are functional properties, fiber materials and further information on composition mentioned by the supplier. The sample sock R is a reference material without special promotion as functional textile material

No.	Mentioned functional properties	Fiber materials	Further information given on composition
R	Comfort waistband, warming, high wearing comfort	77 % cotton, 19 % polyamide, 2 % polyester, 2 % elastane	--
1	Antistatic; flame retardant	40 % modacrylic, 26 % cotton, 25 % polyamide, 6 % elastane, 3 % conductive fibers	---
2	Coolmax, kevlar	45 % polyester, 25 % cotton, 20 % polyamide, 6 % elastane, 4 % aramid (Kevlar)	---
3	Coolmax Core; ESD-fähig “antistatic”, Si Repel Mosquito	43 % polyester Coolmax, 32 % polyamide, 22 % cotton, 2 % elastane, 1 % other fiber materials	Impregnated with biocidal product
4	Humidity up-take, breathable, antibacterial, prevents odor formation	43 % bamboo, 35 % polypropylene, 20 % polyamide, 2 % elastane	---
5	Durable, thermal-insulating, antibacterial, anti-allergic, quick-drying	46 % polyester, 25 % polypropylene, 19 % cotton, 7 % polyamide, 3 % elastane	---
6	Flame retardant, antistatic, breathable	60 % modacrylic, 38 % cotton, 2 % carbon	---

these knitted products. In case of sample products 1 and 6, modacrylic fibers with chlorinated co-unit are used to achieve flame-retardant properties. The use of conductive fibers, as e.g. carbon fibers, leads to antistatic properties. For the sample products 2 and 3 the use of Coolmax fibers is described, which is a special type of polyester fiber exhibiting moisture transport properties. For sample 3 also a repellency to mosquitos is mentioned as functional property, which is reached by impregnation with a biocidal product. Sample product 3, is also described to be “ESD-fähig” (antistatic). This antistatic property can be related to the 1 % of other fiber materials, which composition is not disclosed in detail. Sample 4 is in this overview the only sample with bamboo fiber, which is probable a regenerated cellulose fiber based on bamboo as material source (Alvarez, Ławińska & Falkiewicz-Dulik, 2020). Remarkable is the use of polypropylene fibers in the product samples 4 and 5, because the use of this fiber is quite uncommon for clothing application. However, the application of the hydrophobic polypropylene fiber might be supporting the claimed quick-drying and breathable effects. Also, an influence on friction coefficients is reported (Zhang et al., 2023).

Analytical Methods

Microscopic investigations are done by scanning electron microscopy using a Tabletop microscope TM3000 from Hitachi (Japan). The samples are investigated as received and no further pretreatment is done before microscopic measurements. The thermal properties of the socks are evaluated using a heat camera type FLIR-P640 (InfrarotTec Systems, Ranstadt, Germany). For thermal insulation measurements, all socks are investigated in worn condition by using the heat camera. For reference, a measurement is done at bare feet. To ensure comparability of the results, the foot was acclimatized, by being barefoot for a minute between each measurement. By using the heat camera, a photo is recorded after wearing the sock for three minutes. Examples for such photographs are presented in Figure 2. Afterwards the camera recorded the temperature of the foot at three different points – the ball of the foot, on the instep and on the heel.

Microscopic investigations

The structure of the knitted fabrics and the yarn structure of all seven products are evaluated by scanning electron microscopy (SEM). SEM images taken in low and medium magnification are presented in Figures 3 and 4.

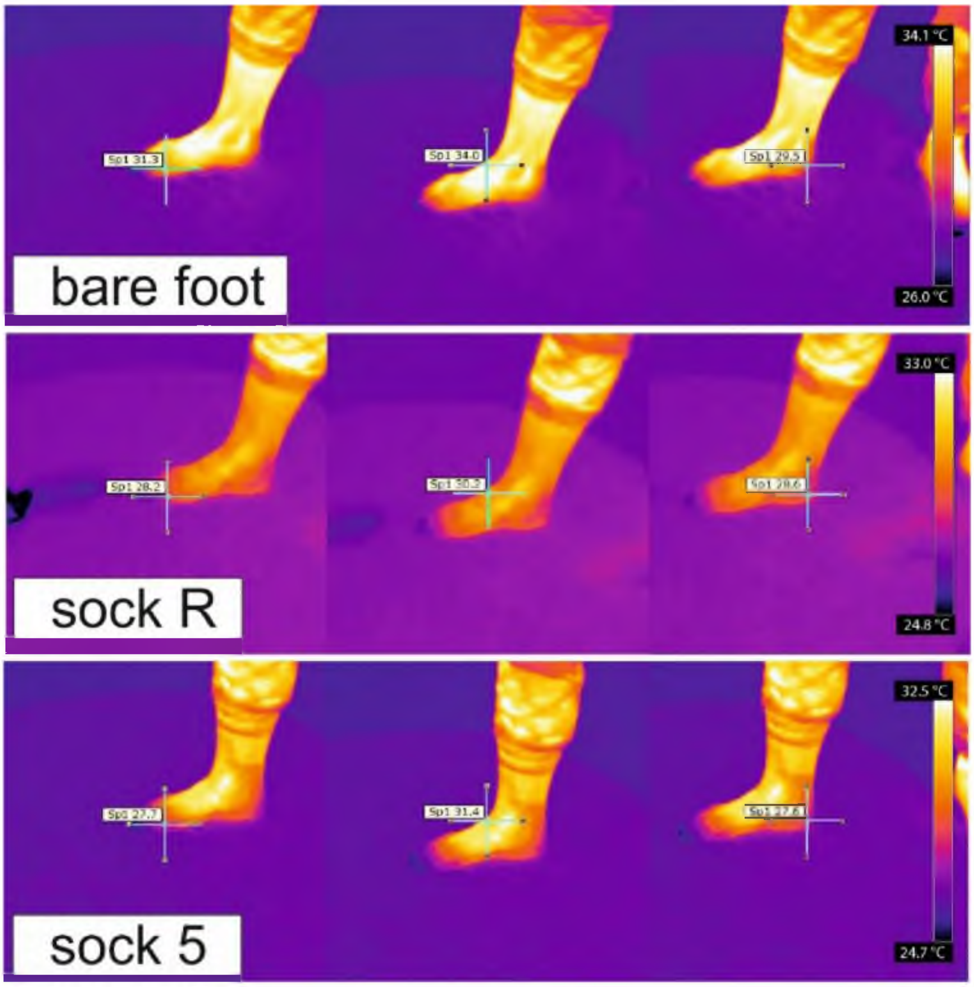

Figure 2 – Images taken with heat camera on bare foot and foot covered by different socks. The temperatures are recorded after three minutes at three different positions of the foot (ball, instep, heel)

These images are recorded from samples taken from the shaft of the socks. For the reference sample, mainly the cotton fibers are determined. For samples 2 and 6, fibers are detected in different brightness according to a material contrast. Materials containing chemical elements with higher atomic number (as e.g. chlorine) appear brighter in SEM images (Mahltig & Grethe, 2022). By this, the chlorine containing modacrylic fiber can be distinguished from cotton or polyester. For both samples the modacrylic fiber is part of a blended yarn introduced to the knitted fabric. In higher magnification, the SEM images of sample 6 exhibits also bright dots onto the acrylic fibers. These dots might be related to the addition of antimony oxide Sb_2O_3, which is a catalyst known for supporting the flame-retardant properties of halogen containing organic materials (Zhang et al., 2023).

Thermal investigations

The investigation of thermal insulation properties, is done by determination of the surface temperature of the foot carrying the socks. The surface temperatures are determined at three different positions of the foot – the ball, instep and heel. Among these positions, for the instep the highest temperature is determined. Reference measurements are done with the bare foot. For the bare

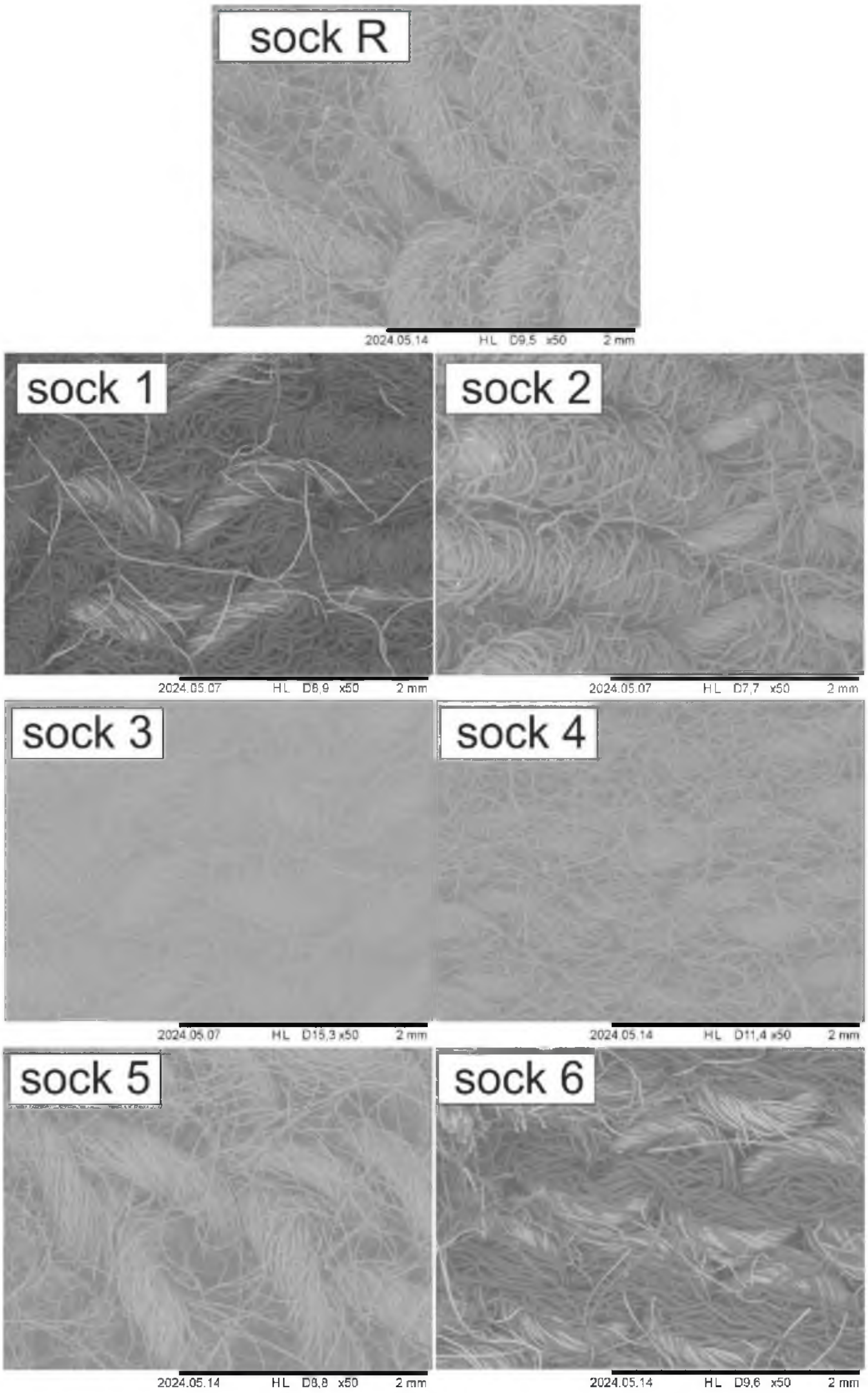

Figure 3 – Microscopic images of the different socks recorded with scanning electron microscopy in low magnification. Samples for microscopy are taken from the shaft of the socks

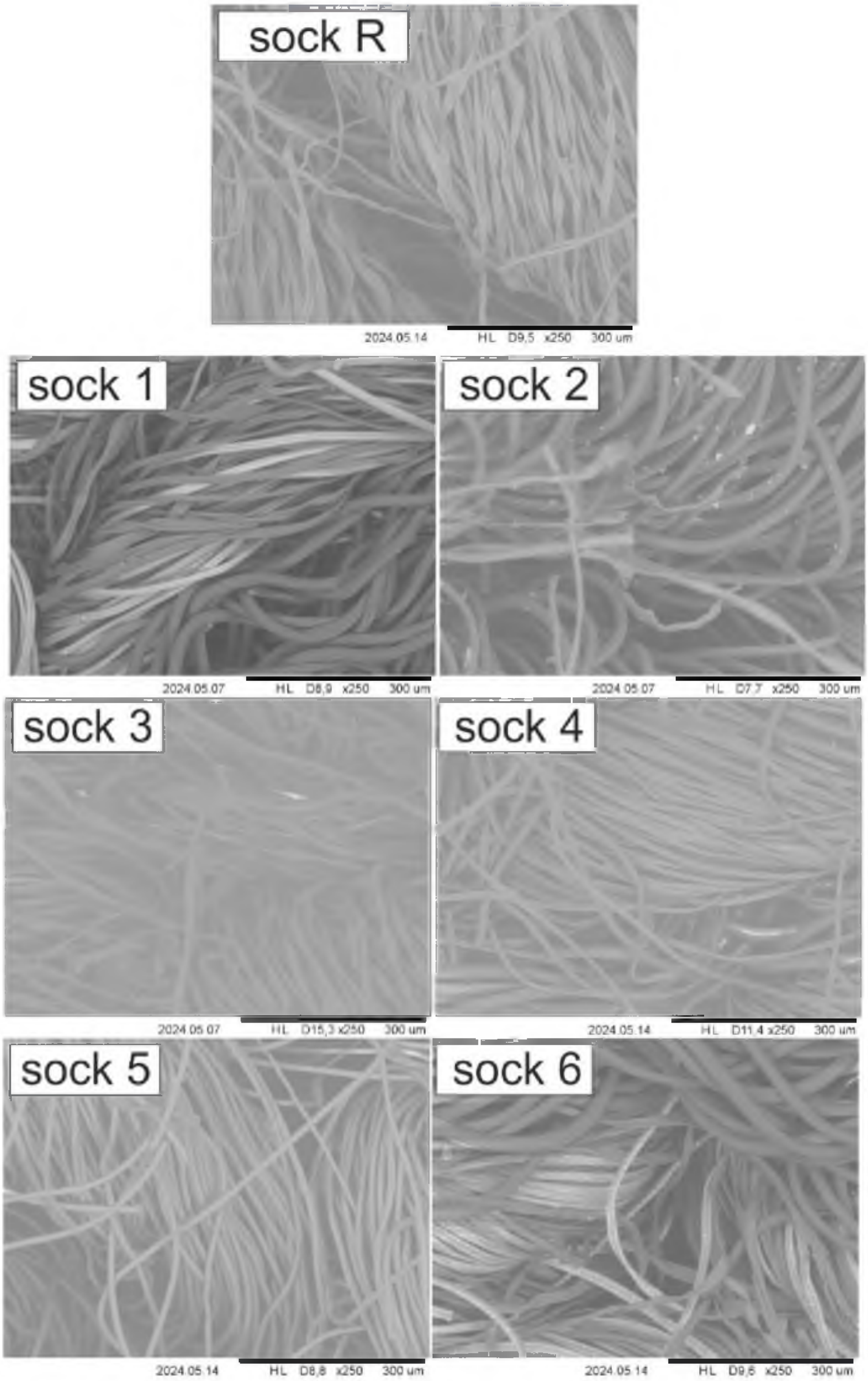

Figure 4 – Microscopic images of the different socks recorded with scanning electron microscopy in medium magnification. Samples for microscopy are taken from the shaft of the socks

foot, surface temperatures in the range of 29.5 to 34 °C are determined, which are below the body temperature of 36 °C for humans. A foot covered by the reference sample sock R shows a significantly decreased surface temperature. This decreased surface temperature indicates a thermal insulation caused by the sock. This effect is strongest for the measurement area of the instep. The functional socks 1 to 6 exhibit results strongly dependent on the measurement area. For the ball area, the thermal insulation of the functional socks is quite similar to the reference sock. Here, sample sock 4 exhibit the highest thermal insulation and sample sock 1 the lowest insulation (even lower than the reference sock). For the instep area, all functional socks exhibit higher surface temperatures compared to the reference sock, so a kind of cooling effect might be claimed. However, this cooling effect can be only claimed in comparison to the conventional sock and not to the bare foot. For the heel area, the functional socks 1 to 3 are quite similar to the conventional sock but the socks 4 to 6 exhibit significant lower thermal insulation properties. Based on these measurements, overall for the product samples 4 to 6 it is justified to claim a cooling effect comparable to conventional socks.

Summary & conclusions

In the area of functional textiles, there are many options for equipment, properties and manufacturing processes to produce them. Combining different materials opens up additional possibilities. As well as through the use of fiber mixtures and high-performance fibers. The seven textile socks tested differ greatly in their material composition, but also have some similarities. All socks contain a certain percentage of cotton, except for the sample 4, which uses bamboo instead. In addition, the socks, with the exception of sample 6, contain elastane to increase elasticity and fit. The main properties resulting from the material compositions of the socks are clearly different, as each sock is tailored to its specific purpose. Their thermal insulation capacity fluctuates accordingly. However, the measured surface temperatures might differ from the personal impression of consumers, due to personal circumstances. Not only the insulation performance and material composition are crucial for wearing comfort, but also the surface construction of the product. All socks have heel and toe areas reinforced with terry cloth. The reference sock does not have any extra reinforced areas as it is a full terry cloth sock. In conclusion, it can be stated that the thermal insulation performance of socks is an important property contributing significantly to the wearer's subjective perception of comfort. Since every person finds a different temperature comfortable, it might be difficult to make a uniform statement about the insulation performance of socks. What counts here is not just the subjective perception of the wearer, but also the combination of the material and other functional properties of the sock. Measured values, manufacturer information and material compositions give the consumer an information as to whether the product might be suitable for their intended use and their personal body feeling. However, the consumer only gains real security

Table 3 – Temperature overview after thermal tests on the socks; the surface temperature determined at different foot positions in comparison to the bare foot and the reference sock R

	Ball			Instep			Heel		
	Temp.	ΔT Fuß	ΔT S R	Temp.	ΔT Fuß	ΔT S R	Temp.	ΔT Fuß	ΔT S R
bare foot	31.3 °C			34.0 °C			29.5 °C		
Sock R	28.2 °C	-3.1 °C		30.2 °C	-3.8 °C		28.6 °C	-0.9 °C	
Sock 1	29.3 °C	-2.0 °C	1.1 °C	32.3 °C	-1.7 °C	2.1 °C	28.7 °C	-0.8 °C	0.1 °C
Sock 2	28.4 °C	-2.9 °C	0.2 °C	31.9 °C	-2.1 °C	1.7 °C	28.5 °C	-1.0 °C	-0.1 °C
Sock 3	28.0 °C	-3.3 °C	-0.2 °C	32.1 °C	-1.9 °C	1.9 °C	28.2 °C	-1.3 °C	-0.4 °C
Sock 4	26.9 °C	-4.4 °C	-1.3 °C	30.9 °C	-3.1 °C	0.7 °C	27.3 °C	-2.2 °C	-1.3 °C
Sock 5	27.7 °C	-3.6 °C	-0.5 °C	31.4 °C	-2.6 °C	1.2 °C	27.6 °C	-1.9 °C	-1.0 °C
Sock 6	28.1 °C	-3.2 °C	-0.1 °C	30.7 °C	-3.3 °C	0.5 °C	27.3 °C	-2.2 °C	-1.3 °C

through their own experience wearing it. It is advisable to focus on objectively assessable functions such as flame protection, antistatic properties or antibacterial features and to treat subjectively assessable properties (insulation performance, weight, compression) as a secondary priority.

Conflicts of interest

The authors declare no conflict of interest in the authorship or publication of this paper. All product and company names mentioned in this article may be trademarks of their respected owners, even without labeling.

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