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SPORTS TEXTILES WITH ADAPTIVE WATER ABSORPTION AND TRANSFER CAPABILITY

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Abstract: *In sports textiles, continuous growing and one of the biggest markets, changing customer expectations in the direction of 'maintaining comfort in all conditions', have created demand for textile structures having smart comfort functions in dynamic conditions. In this manner, adaptive water absorption and also transfer capability depending on the environment and body conditions for sportswear could provide a drier and more comfortable feeling during intense sweating. For developing sport textiles with adaptive water absorption and transfer capability; conventional knitted cotton and regenerated cellulosic fabrics (cotton, recycled cotton, viscose, modal, lyocell, bamboo), mostly used in sports textiles, were treated with temperature-water sensitive shape memory nanocomposite for adaptive water absorption capacity and transfer features by keeping the acceptable fabric hand features. Adaptive water absorption and transfer capability of the fabrics were measured by modified drop, immersion period, and absorption capacity tests using water at different temperatures (20°C and 40°C). Also, presence of coating on fabrics' surface and fabric-nanocomposite interactions were detected by SEM and FT-IR analysis, respectively. According to results, temperature-water responsive nanocomposite treated viscose knitted fabric having acceptable bending rigidity increment comparing to their raw forms and also adaptive liquid absorption period and capacity features, can be suggested for a smart sports textile.*

Keywords: *Adaptive Wettability; Adaptive Wicking; Adaptive Water Absorption; Cellulosic Fabric*

1. INTRODUCTION

Sports textiles have a continuous growing market despite the economic crisis and all other problems such as pandemic. Having one of the biggest market increments as people are paying more attention to sports activities [1], sports clothing are generally produced from knitted fabrics; especially those produced from cotton and regenerated cellulosic fibre (viscose, lyocell, modal, micromodal, bamboo, etc.) blends with synthetics. Although passive comfort enhancements can be achieved by choosing the proper material (blend, cross section, etc.) and fabric construction, the mentioned methods are generally inadequate to adapt dynamic changes of the environment (temperature and humidity) and body physiological changes (body temperature, sweating rate). Therefore, many researchers and industries have engaged to develop textile structures having smart comfort functions in dynamic conditions. Currently, shape memory polymers enabling adaptability to dynamic environmental and body physiological changes such as temperature and moisture (sweat) by changing porosity of the structure have wide application potential in sportswear area [2]. Among commercial shape memory polymers, temperature responsive shape memory polyurethane (SMPU) is the most suitable one for smart textile applications in the form of film, fiber, and finishing treatment/coating, achieving adaptive comfort by adjusting porosity of the structure as a result of molecular mobility increase [3]. On the other hand, shape memory-based smart textile

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structures responsive to one stimulus, mainly temperature, has limited adaptive comfort features due to the higher activation temperature, response time, and concentration required for sufficient shape memory effect. As well as temperature, moisture/water is also important in managing clothing comfort as people can sweat in both high and low temperatures under high degree of workload. Dynamic adaptability is also crucial for wettability, wicking and water/sweat absorption capacity of fabric, more important that breathability under specific conditions. The dynamic wetting, wicking and absorption features, meaning a performance improvement with temperature, is particularly beneficial for sportswear for creating a drier and more comfortable feeling during intense sweating. In this manner, developing temperature-water responsive materials having dynamic sweat absorption and transfer features can be advantageous for smart comfort enhancement in sportswear. To develop dual-responsive shape memory structures, hydrophilic particles such as cellulose nanowhiskers (CNWs) can be introduced to temperature-responsive matrix polymer (SMPU) [4]. Reversibly broken hydrogen bonds among CNWs with moisture and plasticisation effect of polymer are the reasons of moisture responsive function created by CNWs. Therefore, in this study, it is aimed to develop adaptive water absorption capacity and transfer features for cellulosic knitted fabrics (cotton, recycled cotton, viscose, modal, lyocell, bamboo) with simultaneously temperature-water/moisture responsive SMPU-CNW nanocomposite treatment.

2. MATERIALS AND METHODS

Single jersey knitted fabrics were produced with cotton (CO), 15/85 recycled cotton/cotton (re-CO), viscose (CV), modal (MD), lyocell (LYC), and bamboo (BAM) Ne 28/1 ring spun yarns. Fabrics were knitted with a Pilotelli Circular Knitting Machine having a diameter of 30 inches and a gauge of 28 E. The fabrics were treated with temperature-water/moisture responsive shape memory nanocomposite to develop adaptive wettability, wicking, and water absorption features. For this aim, the shape memory nanocomposite structure was produced by using commercial SMPU polymer matrix, having appropriate T_{trans} temperature of 32°C for body temperature, and CNWs having a length of 150-200 nm and width of 20 nm (by TEM) and crystallinity of 98.98%, as water responsive nano-reinforcing material. First, SMPU polymer was dissolved in dimethyl acetamide, an eco-friendly solvent at 8wt% concentration according to preliminary studies for keeping fabric bending rigidity within acceptable limits. In the next step, the suspension was transferred into CNW-dimethyl acetamide-surfactant (Tween®80, nonionic surfactant) suspension having nanoparticle concentration at 20 wt% of polymer by ultrasonic stirring (Sonopuls HD 2200, Bandelin Sonopuls Corp.) for 1 h at 40 Watt, 40% amplitude and 3-s on/off cycles. Finally, the cellulosic single jersey knitted fabrics were treated with the produced nanocomposite suspension by a pad-dry-cure process (3 bar pressure, 2 m/min speed, 90% wet pick up and drying at 90°C for 5 min and curing at 120°C for 5 min). Neat SMPU treatment was applied to the fabrics with the same application procedure for comparison.

The scanning electron microscopes (SEM, Fei Quanta FEG 250) with an accelerating 20 kV voltage and 10 µA current of at 3000 magnification were utilized to investigate the morphologies of the selected raw and SMPU and nanocomposite (SMPU-CNW) treated fabrics. Fourier-transform infrared spectroscopy (FT-IR, JASCO FT/IR 4700 spectrometer) (range from 400-4000 cm^{-1}, 2 cm^{-1} interval and 16 scan) at room temperature was applied for the chemical structure analysis. Weight and bending rigidity properties were determined according to TS EN 12127 and ASTM D 1388-92:2002, respectively. Shape memory based adaptive water absorption and transfer capability of the fabrics were measured by modified test procedures, which have not been conducted before according to the existing literature. Absorbency of the samples were tested by a modified drop test according to AATCC 79:2018 using water at different temperatures (20°C and 40°C). Immersion period test giving idea about both wetting and wicking performances was conducted according to AATCC 79-Method B at 20°C and 40°C water temperatures. Adaptive absorption capacity function was determined by weight changes of samples kept in distilled water at different temperatures (20°C and 40°C) for a total of 30 minutes according to a preceding study [6]. Fabric samples were conditioned for 24 h at standard atmospheric conditions according to the TS EN ISO 13934-1:2013 prior to performance tests.

Statistical analysis was carried out using a Univariate ANOVA method followed by Student-Newman-Keuls post hoc test using SPSS 22.0 for Windows statistical software (IBM, Armonk, USA). A *p* value less than 0.05 was considered as significant.

3. RESULTS AND DISCUSSIONS

According to the results, SEM images in Figure 1 present the successful immobilization of the nanocomposite on/among fibers of all fabric types. The presence of nanocomposites in the SEM images was also detected by FT-IR spectra as seen in Figure 2.

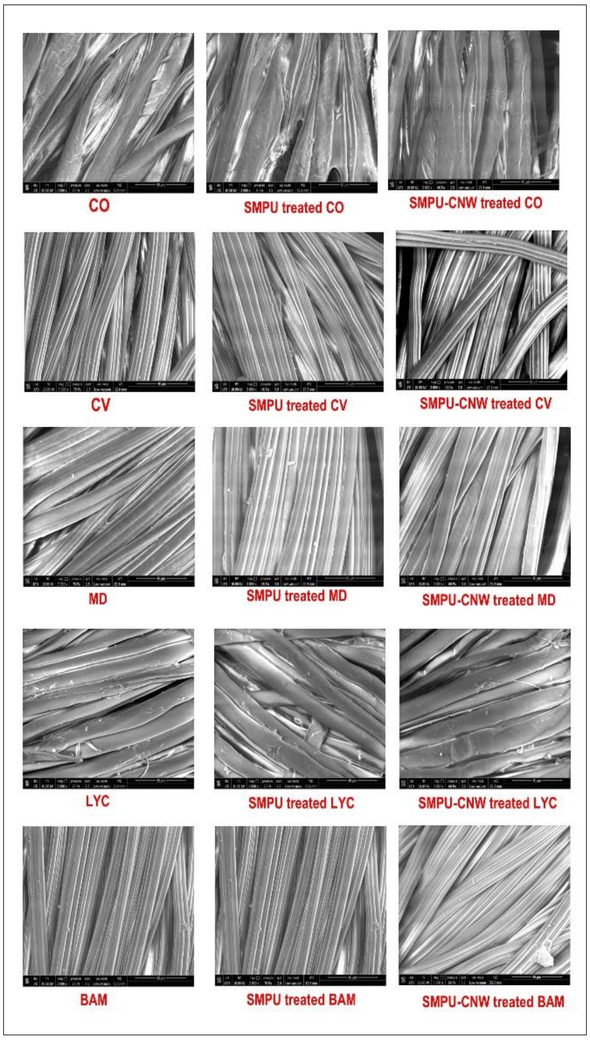

Figure 1. SEM images of raw, SMPU and SMPU-CNW nanocomposite treated fabrics

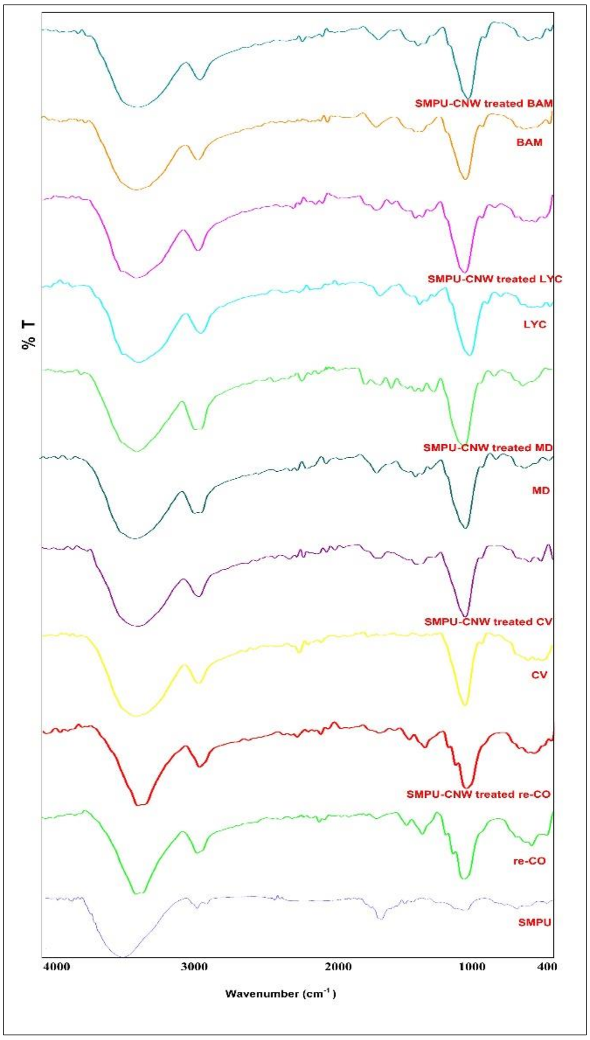

Figure 2. FT-IR spectrum of raw, SMPU and SMPU-CNW nanocomposite treated fabrics

The characteristic peaks of SMPU granules (Figure 2); (-NH) stretching vibration of urethane at around 3449 cm^{-1}, (-CH$_2$) stretching at 2861 cm^{-1} and 2927 cm^{-1}, (C=O) stretching at 1737 cm^{-1}, other modes of (-CH$_2$) vibrations at 1463, 1406, 1345, and 1294 cm^{-1} and (-NH) 1544 cm^{-1} are approximately visible in the FT-IR spectrum of SMPU polymer granules. The characteristic peak at 10541 cm^{-1} belong to ether group ($-C_2H_4-O-C_2H_4-$). Since all fibres used for knitted fabrics are cellulosic, (-OH) stretching band in the wavelength range of 3200-3400 cm^{-1} and (C-H) stretching peak of hydrocarbon structure of hemicellulose around 2900 cm^{-1} wavelength were observed in all raw fabrics. The peak at 1737 cm^{-1} for SMPU polymer can be attributed to the free urethane (C=O) groups (Figure 2), while the peak at approximately 1700 cm^{-1} for SMPU-CNW treated fabrics indicates the hydrogen-bonded urethane (C=O) groups and also indicator of polymer presence in the fabric structure. A decrease in the intensity of (-OH) stretching band in the wavelength range of 3200-3400 cm^{-1} and (-OH) in-plane stretching band in the range of 900-1200 cm^{-1} for nanocomposite treated fabrics in comparison with the raw ones indicate that the SMPU polymer reacts with the (-OH) groups of all cellulose-based fabrics used in the study.

Physical features of the raw and treated fabrics were compiled in Table 1. According to the statistical analysis, raw material, treatment type, and two-way interactions of both have significant effects on fabric areal density values ($p=0<0.05$). As the areal density values were evaluated according to raw material, the highest weight values belong to MD, LYC, and BAM fabrics. Besides, as the areal density values were evaluated according to the treatment type, as expected, the fabric areal density values increased significantly with all treatments ($p<0.05$) and reached the maximum values SMPU-CNW except for the re-CO fabric. Similar trend was observed for bending rigidity that raw material, treatment type, and two-way interactions of them have significant effect on bending rigidity ($p=0<0.05$). As seen in Table 1, the maximum and minimum bending rigidity values belonged to CO fabrics and modal in turn. This performance may be attributed to the highest crystallinity of cotton fibres and lower inter-fiber movement as a result of specific cross-section and surface features of cotton. On the other hand, among the regenerated cellulosic fibres, MD and BAM have lower bending rigidity values, mainly sourced from the fibre crystallinity ratios. Fibre surface features also have an influence that rough fiber surface facilitates the movement of fibers relative to each other by increasing the specific fiber surface [2, 4, 7-9], a phenomenon partially valid for this study. As expected, the bending rigidity of fabrics increased with SMPU and nanocomposite treatment and reached a maximum for CO fabrics, in harmony with their raw forms. The polymer, decreasing relative movement of fibers significantly increase the bending rigidity of an individual fibre, and the overall fabric [2, 4]. On the other hand, while the nanocomposite treatment increased fabric bending rigidity compared to the raw form, a significant decrease ($p=0<0.05$) was observed compared with the SMPU treated ones. Relative decrease in bending rigidity of all fabrics with nanocomposite treatment may be due to the plasticisation effect of hydrophilic CNW particles with ambient relative humidity [2, 4].

Table 1. Physical features of cotton and regenerated cellulosic fabrics

Sample code	**Areal density (g/m^2) [S.D]**			**Bending rigidity (mg.cm) [S.D.]**		
	Raw	**SMPU**	**SMPU-CNW nanocomposite**	**Raw**	**SMPU**	**SMPU-CNW nanocomposite**
CO	200 [1.48]	195 [7.21]	200 [7.94]	120.44 [53.29]	773.62 [121.91]	660.15 [119.31]
re-CO	195 [1.87]	202 [3.21]	199 [4.78]	115.51 [40.19]	739.38 [91.92]	660.51 [112.75]
CV	199 [3.91]	195 [7.83]	211 [2.55]	49.92 [21.49]	163.16 [36.19]	99.05 [19.13]
MD	203 [3.21]	222 [6.68]	244 [5.09]	24.04 [2.90]	103.35 [16.23]	40.31 [10.23]
LYC	214 [3.40]	215 [3.67]	230 [1.02]	60.94 [2.89]	148.96 [1.57]	120 [28.32]
BAM	224 [1.41]	218 [13.96]	231 [19.75]	36.84 [7.19]	219.57 [32.29]	154.41 [20.S33]

Sweat absorption/transfer features are important functions for sportswear fabrics investigated in this study. The adaptive absorption of the liquid by the inner side of cellulosic knitted fabrics were investigated by modified drop test and results were given in Figure 3. According to the results, absorption period values varied significantly ($p=0<0.05$) with all parameters and their interactions. As the results were evaluated according to raw materials, re-CO fabrics absorbed liquid in the shortest time followed by CO ones. On the other hand, regenerated cellulosic fabrics; MD having the maximum values, absorbed liquid within longer periods, contrary to the result of a previous study [8]. Among the regenerated cellulosic fabrics, LYC fabrics absorbed liquid in a shorter time followed by BAM. This can be explained by rougher fiber surface of MD and CV [7], reducing the surface energy of these fabrics and preventing the penetration of liquid into the fabric. As expected, the absorption periods of all fabrics significantly increased with SMPU treatment compared to the raw ones. Liquid was not absorbed by the samples even after 180 s, especially for SMPU treated CO, CV, and MD as a result of hydrophobic nature of SMPU. On the contrary, all SMPU-CNW treated fabrics absorbed water within significantly shorter periods (than raw and SMPU-treated ones) and the mentioned decrease trend continued significantly with water temperature. 5-s limit was recorded for nanocomposite treated CO (5.59 s), re-CO (2.9 s), and BAM (3.45 s) fabrics. The performances of nanocomposite treated LYC and CV are also acceptable, with periods of approximately 7 s. The mentioned result can be attributed to the porosity increase with temperature, showing the effect of temperature-responsive SMPU matrix and debonding of H bonds among hydrophilic CNWs within water (effect of moisture-responsive nanofiller).

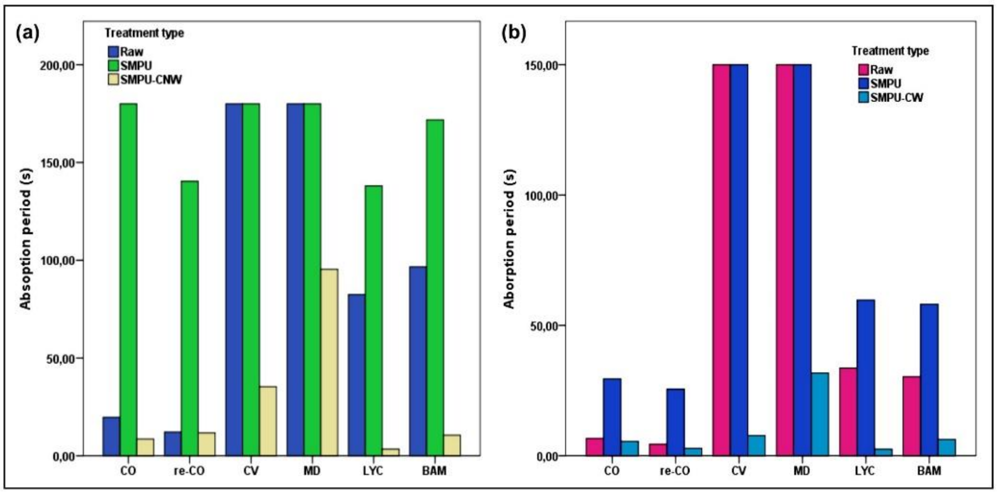

Figure 3. Absorption period of the fabrics at 20°C (a) and 40°C (b)

In harmony with the absorption period test results, differences among immersion periods of the fabrics were significant ($p<0.05$) (Table 2). LYC fabrics did not sink in any form, including in their raw forms besides the raw forms of CV and MD. Moreover, none of the SMPU treated fabrics sinked, in harmony with the wetting results. For all fabric types (except for LYC), SMPU-CNW nanocomposite treatment ensured a great reduction in the sinking periods, especially at 40°C. SMPU-CNW nanocomposite treated fabrics were immersed in liquid within 30.02-10.26 s at 20°C, 11.03-4.22 s at 40°C reaching the minimum values for CO (4.22 s for re-CO 6.04 s for CO) and BAM (6.07 s) fabrics at 40°C, values around the limit of 5-s for thermal comfort of cellulosic fabrics [1]. Reduction in immersion periods can also be attributed to the hydrophilicity increment with CNW particles. In addition, temperature responsive shape memory effect of SMPU matrix and (40°C, the temperature value above T_g) and extra micro-voids formation/increase due to stretching and breaking of hydrogen bonds among CNW particles with temperature [2], creates more fluid transfer channels and increases fluid transmission with capillary force. Better performances of cotton fabrics can be linked to lumen part of cotton fiber absorbing water, providing faster transfer with the effect of capillary force [10].

Table 2. Immersion period values of fabrics

Immersion period (s) [S.D.]						
Samples	**Raw**		**SMPU**		**SMPU-CNW**	
	20°C	**40°C**	**20°C**	**40°C**	**20°C**	**40°C**
CO	16.03^{b} [8.11]	9.32^{ab} [2.38]	-	-	19.91^{bc} [9.00]	6.04^{a} [2.11]
re-Co	9.11^{ab} [0.68]	6.62^{a} [0.387]	-	-	24.31^{c} [15,51]	4.22^{a} [0.55]
CV	-	-	-	-	10.65^{ab} [2.17]	8.0^{ab} [1.9]
MD	-	-	-	-	30.02^{cd} [6.04]	11.03^{ab} [2.1]
LYC	-	-	-	-	-	-
BAM	70.78^{f} [6.98]	50.26^{e} [6.49]	-	-	10.26^{ab} [3.34]	6.07^{a} [1.30]

*: Different superscript letters show statistically significant differences.

Absorption capacity values of the fabrics, a property related to the macromolecular structures of the fibers besides physical features are given in Figure 4. As well as absorption and immersion periods, the absorption capacity of the fabrics differed significantly ($p<0.05$) with all the investigated parameters and their interactions. The water absorption capacity values increased with temperature for SMPU-CNW treated fabrics. Maximum and statistically identical values, even higher than raw ones, belonged to SMPU-CNW treated CV, BAM, and MD fabrics at 40°C. At temperature above T_g of SMPU matrix (40°C), water molecules could interact with the hydrophilic nanoparticles in crystalline regions as well as the amorphous regions with the effect of temperature for SMPU-CNW treated fabrics, providing higher absorption capacity values. Also, formation of porous structure where more water molecules can be absorbed with temperature-sensitive free volume change in soft segments of SMPU matrix and molecular mobility with temperature [2] resulted in dynamic absorption capacity.

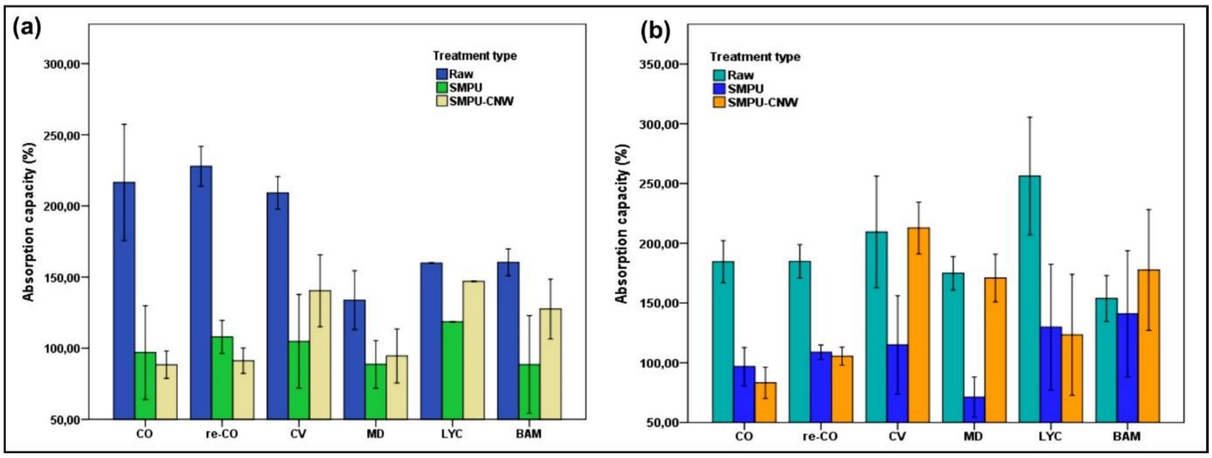

Figure 4. Water absorption capacity of the fabrics at 20°C (a) and 40°C (b)

4. CONCLUSION

Temperature-moisture responsive regenerated cellulosic knitted fabrics were produced by SMPU-CNW nanocomposite finishing treatment. Nanocomposite treatments generally deteriorate the hand values of fabrics but in this study an optimization was carried out to keep the superior hand values of regenerated cellulosic knitted fabrics. By limiting the bending rigidity increment of CV (viscose) compared to their raw forms, it can be suggested for a temperature-water responsive smart fabric with enhanced liquid absorption period and capacity features. Moreover, recycled cotton has also superior performances for wetting and immersion periods despite its deteriorated hand with very high bending rigidity. Summing up, considering the demanded criteria for smart sport textiles consisting hand and adaptive functions, temperature-water responsive nanocomposite treated viscose knitted fabric could be suggested for summer sports as well as winter sports where intense sweating may occur.

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REFERENCES

[1] Kaplan, S., Yilmaz, B., *Thermal Comfort Performances of Double-Face Knitted İnsulation Fabrics*, In: Fibers Polym., 2022, 1-9

[2] Korkmaz Memiş, N., Kaplan, S., *Smart Polyester Fabric with Comfort Regulation by Temperature and Moisture Responsive Shape Memory Nanocomposite Treatment*, In: J. Ind. Text., 2022, 7920S-7941S, https://doi.org/10.1177/1528083720975652

[3] Wang, Y., Yu, X., Liu, R., Zhi, C., Liu, Y., Fan, W., Meng, J., *Shape Memory Active Thermal-moisture Management Textiles*, In: Compos. Part A Appl. Sci. Manuf., 107037, https://doi.org/10.1016/j.compositesa.2022.107037

[4] Korkmaz Memiş, N., Kaplan, S., *Dual Responsive Wool Fabric by Cellulose Nanowhisker Reinforced Shape Memory Polyurethane*, In: J. Appl. Polym., 2020, 137, 19, 48674, https://doi.org/10.1002/app.48674

[5] Yu, S., Sharma, R., Morose, G., Nagarajan, R., *Identifying Sustainable Alternatives to Dimethyl Formamide for Coating Applications Using Hansen Solubility Parameters*, In: J. Clean. Prod., 322, 129011, https://doi.org/10.1016/j.jclepro.2021.129011

[6] Tang, K. P. M., Kan, C. W., Fan, J. T, *Evaluation of Water Absorption and Transport Property of Fabrics*, In: Text. Prog., 46, 1, 1-132, https://doi.org/10.1080/00405167.2014.942582

[7] Riaz, M. T., Khan, M. I., Shaker, K., Nawab, Y., Umair, M., *Effect of Cellulosic Material and Weave Design on Comfort Performance of Woven Fabrics*, In: J. Nat. Fibers., 2023, 20, 1, 2163030, https://doi.org/10.1080/15440478.2022.2163030

[8] Kaplan, S., Karaman, C., *Skin-fabric Friction and Other Performance Characteristics of Socks Fabrics Produced from Cellulosic Fibers*, In: Text. Appar., 2018, 28, 3, 213-220.

[9] Basit, A., Latif, W., Baig, S. A., Rehman, A., Hashim, M., Rehman, M. Z. U., *The Mechanical and Comfort Properties of Viscose with Cotton and Regenerated Fibers Blended Woven Fabrics*, In: Mater. Sci., 2018, 24, 2, 230-235, https://doi.org/10.5755/j01.ms.24.2.18260