(REFEREED RESEARCH)

ELASTIC BANDAGES WITH IMPROVED COMFORT PROPERTIES

KONFOR ÖZELLİKLERİ GELİŞTİRİLMİŞ ELASTİK BANDAJLAR

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ABSTRACT

Elastic bandage samples were produced on a crochet knitting machine utilizing some special polyester, cotton and viscose yarns. Air permeability, porosity, thermal conductivity, thermal absorbtivity, thermal resistance and water absorbency of these bandages were compared. Results revealed that air permeability depended on fabric density and porosity. Capillarity action played a significant role in water absorbency. Particularly, channeled fiber structure improved water absorbency in a great extent. Thermal conductivity was affected by fiber type and fabric density. Cotton and viscose fibers, and dense fabric structure caused high thermal conductivity. Thermal resistance showed an opposite trend. In addition, in order to improve thermal comfort characteristics of the bandages phase change material (PCM) loaded microcapsules were applied to one of bandage samples. Alambeta test results confirmed that application of PCM microcapsules improved the thermal comfort properties of bandages in some extend.

Keywords: Elastic bandage, thermal comfort, air permeability, water absorbency, phase change material, microcapsule

ÖZET

Özel poliester, pamuk ve viskon iplikleri kullanılarak kroşe örgü makinesinde elastik bandaj numuneleri üretilmiştir. Bu bandajların hava geçirgenlik, gözeneklilik, ısıl iletkenlik, ısıl soğurganlık, ısıl direnç ve su emicilikleri kıyaslanmıştır. Sonuçlar hava geçirgenliğinin kumaş yoğunluğu ve gözenekliliğe bağlı olduğunu ortaya koymuştur. Kapilarite su emiciliğinde önemli bir rol oynamaktadır. Özellikle, kanallı lif yapısı su emiciliğini büyük ölçüde iyileştirmektedir. Isıl iletkenlik lif tipi ve kumaş yoğunluğundan etkilenmektedir. Pamuk ve viskon lifleri ve sıkı kumaş yapısı yüksek ısıl iletkenliğe sebep olmaktadır. Isıl direnç tam tersi bir eğilim göstermektedir. Ayrıca, bir bandaj numunesine termal konfor özelliklerini geliştirmek için faz değiştirici materyal yüklü mikrokapsüller aplike edilmiştir. Alambeta test sonuçları faz değiştirici materyal yüklü mikrokapsüllerin bandajların ısıl konfor özelliklerini bir miktar iyileştirdiğini doğrulamıştır.

Anahtar Kelimeler: Elastik bandaj, ısıl konfor, hava geçirgenliği, su emicilik, faz değiştiren material, mikrokapsül

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1. INTRODUCTION

Medical textiles are a major expanding area in the technical textiles industry. Examples of their application include wound dressings, artificial ligaments, sutures, artificial liver/kidney/lungs, vascular grafts/heart valves, artificial joints/bones, eye contact lenses and artificial cornea, nappies, sanitary towels, surgeons wear and bandages [1]. Elastic bandages are the stretchable textile surfaces used to create localized pressure [2]. They can be used to reduce bleeding and swelling by generating pressure during first aid, to wrap up injuries and fix dressings, and to help healing process of sprains and bruises by immobilizing the injured tissues, joints, muscles, and limbs [3]. They are generally produced in the width of 6 to 15cm depending on application area. For instance a bandage of 6cm is usually preferred for hand and wrist, of 8-10cm width is for forearm and ankle and of 12-15cm width is for knee, calf, shoulder and groin regions [4]. They can also have different level of elasticity up to the usage area. The tension level is depended on the type of construction and/or spandex fiber content of fabric. While the middle level of tension is mostly preferred for the first-aid treatments, strong level is used for supporting wide muscle groups. Elastic bandages can be manufactured in the forms of knitted or woven textiles and in different shapes so they can be used for the different parts of body [5,6]. In sport's medical care and light support treatments the most encountered elastic bandage type in market are produced on crochet knitting machines. Crochet machines are convenient for the production of bandages with their simple construction, ease of pattern and width changing, possibility of individual yarn packages or beams utilization and thus providing the opportunity for short runs on coarse- or fine-gauge structures [7]. Crochet warp knitting structure, in its basic form, relies on attaching of columns to each other, that are formed by the warp yarns, by means of a continuous weft yarn [8]. Bandages can be produced with different kinds of fibers such as cotton, viscose, lyocell, polyester, polyamide or their blends [5,6].

Main design requirements for elastic bandages are optimum support, ease of use and wear comfort for prolong use. Wear or clothing comfort is generally classified into two categories: thermophysiological and sensorial (neuro-physiological) comfort. Thermophysiological comfort is mainly related to the dissipation of metabolic heat and moisture and governed by the thermal resistance, water vapor permeability (breathability), wickability, sorption of water, water resistance, repellency and proofness, and drying rate of the textile material. Sensorial comfort, on the other hand, is related to the interaction between the skin and clothing material and affected by prickliness, itchiness, inflammation, roughness, thermal character (warm/cool feeling), and electrostatic propensity of the textile material [9-18]. All these physical properties are affected by fabric mass, fabric thickness, fiber, yarn, and fabric structures, fabric porosity and cover factor. Comfort properties of elastic bandages depend mainly on fabric and yarn structure and fiber type. Manufacturing system affect structural features of bandages, and in turn, comfort properties such as fabric handle, stretch, air permeability, and thermal comfort. Fiber type influences thermal comfort properties, water absorbency and air permeability. In short, to obtain improved wear comfort a careful selection of fiber material and fabric structure is essential. Another way of improving thermal comfort properties of textiles is the inclusion of phase change materials into them. Phase change materials (PCMs) absorb, store, and release large amounts of latent heat over a defined temperature range when experiencing a phase transition and by doing that they keep the temperature of surroundings more or less constant, and provide both active and passive thermal insulation effects. PCM materials are usually incorporated into textiles in the microcapsule form [19-26]. In medical textiles to regulate the patient's micro climate PCMs are already used in acrylic blankets and bed covers [27]. Moreover, surgical apparel, bandages and bedding material are considered as potential application areas for PCM microcapsules [28].

There have been some studies on the thermal comfort properties of medical textiles, but the majority have been on surgical gowns[29,30,31], gloves and masks [29] and compression stocking [32]. The aim of this work was to investigate comfort properties of elastic bandages produced from different types of yarns. For this purpose bandage samples were produced on a crochet knitting machine utilizing some special polyester, cotton and viscose yarns; subsequently air permeability, porosity, thermal conductivity, thermal absorbtivity, thermal resistance and water absorbency of these bandages were compared. In addition, a preliminary work was carried out to find out the effect of PCM microcapsules on thermal comfort characteristics of these bandages. PCM loaded silk fibroin / chitosan microcapsules were applied to bandages and the effect of PCM microcapsules on thermal conductivity, thermal absorbtivity, and thermal resistance of bandages were examined.

2. EXPERIMENTAL

2.1. Elastic bandages

Bandage samples were produced on 16 gauge Comez 816/LT type crochet machine. Fabric width was chosen to be 15cm. The knitting structure of the bandages is given in Figure 1. In all samples warp thread was two ply, texturized polyamide (PA) yarn (70denier/34 filaments). To feed the weft yarn both front and back weft inlay bars were used. During the bandage production samples were examined visually and by hand, and to obtain the similar coverage and fabric hand the feeding amount was varied between 2 and 3. Figure 2 shows the feeding of weft yarns. As weft micro-blended cotton/polyester yarn (MicBL-Pes/Co), 4-channel and 5-channel polyester yarns (PES-Ch4 & PES-Ch5), regenerated cellulose based antimicrobial yarn (SeaCell) were used. Besides these yarns, some conventional yarns that are preferred frequently in the market like cotton, viscose and polyester were utilized for comparison. The detailed descriptions of all bandage samples are given in Table 1. Unfortunately, it was impossible to obtain the same yarn density for all different fiber types. This shortcoming was considered in the discussion of results.

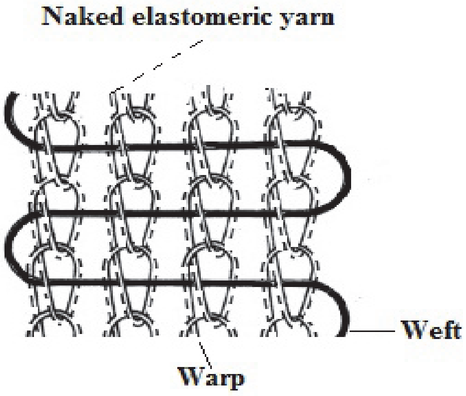


Figure 1. Knitting structure of bandages

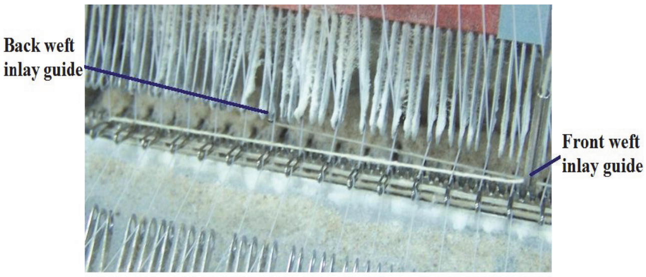


Figure 2. Feeding of weft yarns

Table 1. Description of bandage samples

Sample	Fabric Content	Weft Yarn Feeding Amount		Fabric weight	Wales/cm	Courses/cm	Thickness
Number	*Weft Yarn*	*Front*	*Back*	*(g/m^2)*			*(mm)*
N1	Ne 30/1 Cotton	2	2	356	6	20	1.31
N2	Ne 30/1 Viscose	3	2	397	6	20	1.27
N3	Ne 30/1 PES-Ch4	3	2	381	6	20	1.29
N4	Ne 30/1 MicBL-Pes/Co	3	2	389	6	20	1.32
N5	Ne 30/2 SeaCell	2	2	443	6	19	1.27
N6	150D/144F PES-Ch5	3	2	360	6	20	1.30
N7	Ne 28/2 Viscose	3	2	491	6	17	1.37
N8	Ne 30/2 Cotton	2	2	457	6	18	1.38
N9	Ne 30/2 PES-Ch4	2	2	469	6	18	1.38
N10	150D/96F PES-Ch5	2	2	332	6	21	1.32
N11	150D/36F PES	3	2	346	6	20	1.31
N12	300D/288 F PES-Ch5	2	2	431	6	18	1.36
NIF	150D/72F Texturized PES	3	2	338	6	20	1.18

2.2. Phase change material microcapsules

Preparation of PCM microcapsules

n-Eicosane loaded silk fibroin / chitosan microcapsules were obtained through complex coacervation method described in detail in our previous study [33]. Microcapsules consisted of an average of 45.7 wt% n-eicosane, and had a thermal energy storage and release capacity of about 93.04 J/g and 89.68 J/g, respectively.

Application of microcapsules to the bandages

Microcapsules were applied to the surface of the samples by padding. A polyacrylate based binder (Peripret-PW) from Dr**.** ***Petry*** Textile Auxiliaries was chosen for application of microcapsules to bandages. Bandage samples were impregnated with an aqueous solution composed of 20 g/l of microcapsules and 50 g/l of binder (50 g/l). Padding was done on a Foulard. Afterwards, samples were dried on a stretcher dryer by ATAC Laboratory machines.

2.3. Tests Conducted

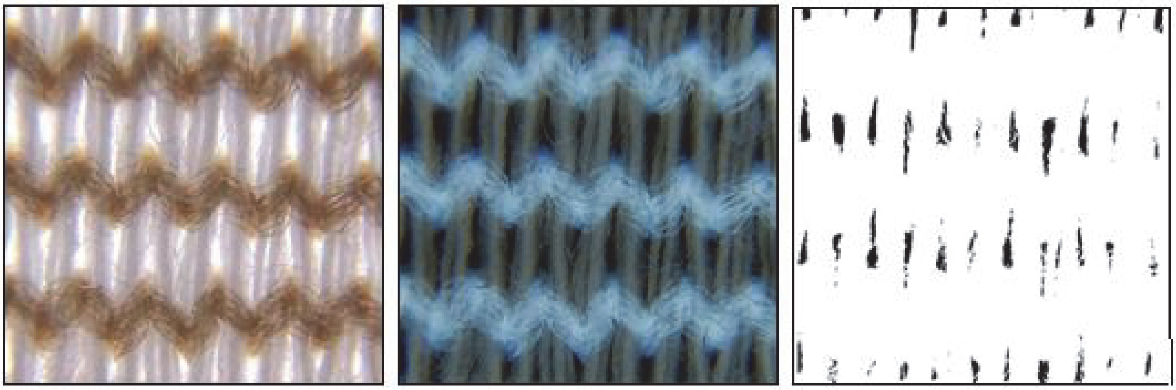
All tests were carried out under standard conditions (21 ± 1°C and 65 ± 2% RH).

Air permeability: The air permeability of the fabrics was measured on a FX-3300 Air Permeability Tester by TEXTEST AG at a test pressure of 100 pa and a test area of 20 cm2 according to DIN 53 887.

Water Absorbency: Three drops of 3% potassium bichromate + 1% red food dye solution were dropped by a pipette on 100 cm^2 circular samples. After 5 minutes photos of samples were taken via a Kodak Z-710 type camera at a fixed distance of 21cm. From these photos spreading of colored liquid was observed.

Porosity: Photos of samples were taken via a Kodak Z-710 type camera at a fixed distance of 3cm. Photos were processed via Corel Paint Shop Pro (Corel PSP) program. First, an area of 5000x5000 pixels was selected (Figure 3a), then the colored image was converted to negative image (Figure 3b) and finally dark areas were isolated by converting the image to a binary image using a specific threshold value (Figure 3c). Number of black colored pixels were counted by an image analysis software (IPS) based on Delphi 2006 programming language [34]. Porosity was calculated by the following equation;

Porosity (%) =(number of black pixels / total number of pixels) x100



a) b) c)

Figure 3. a) Image area of 5000x5000 pixels b) Grayscale c) Isolated dark areas

Thermal Properties: Thermal resistance, thermal conductivity and thermal absorbtivity, of samples were measured on ALAMBETA. This instrument utilizes a heat power sensing system to measure the heat flow passing between the textile sample and the measuring head during contact [35,36].

2.4 Statistical Analysis

Analysis of variance (ANOVA) was used to determine the effect of weft yarn type on the air permeability, porosity, water absorbency and thermal comfort properties of bandage samples. Statistical significance was established at $p < 0.05$.

3. RESULTS

3.1. Air Permeability

Air permeability of a fabric depends on fabric thickness, density and porosity. Air permeability decreases with increasing thickness and density and with decreasing porosity [37]. This property affects fabric comfort extensively. High air permeability results in high water vapor permeability as well. Results from air permeability test are presented in Figure 4. The effect of weft yarn type on the air permeability of bandages was statistically significant. Samples N10, N11 and NIF had high air permeability compared to the rest. Air permeability of samples N7, N8, N9 and N12, on the other hand, was low. As expected coarser yarns used in these samples caused low air permeability. An interesting finding was sample N6 had lower air permeability compared to sample N11 even though both samples knitted from the same count yarn (150 den). This result can be explained by considering the number of filaments these yarns contain. Finer fibers mean higher total surface area and lower air permeability [38].

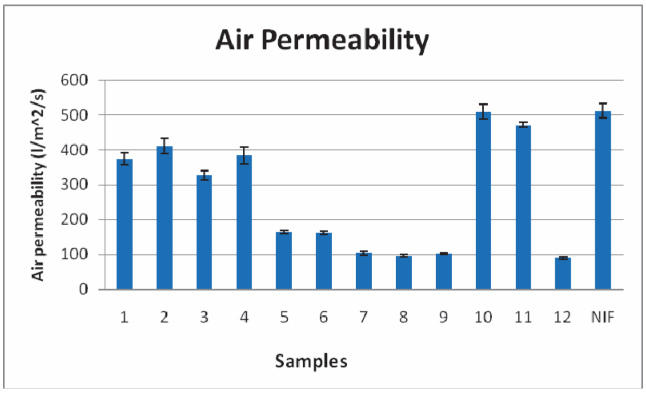


Figure 4. Air permeability of bandages

3.2. Water Absorbency

Our body sweats in order to balance body heat generated during various activities. As a result, the clothing material gets wet where it touches the skin. For wearer comfort this wetness should be removed from the skin immediately, carried away through the outside layers of the clothing and released to the atmosphere in vapor form. The type of fiber and fabric structure have significant effect on the mechanism of liquid transfer. In addition, air channels in the fabric structure helps the removal of moisture in liquid and vapor form. Figure 5 shows water propagation on the surfaces of bandage samples after 5 minutes.

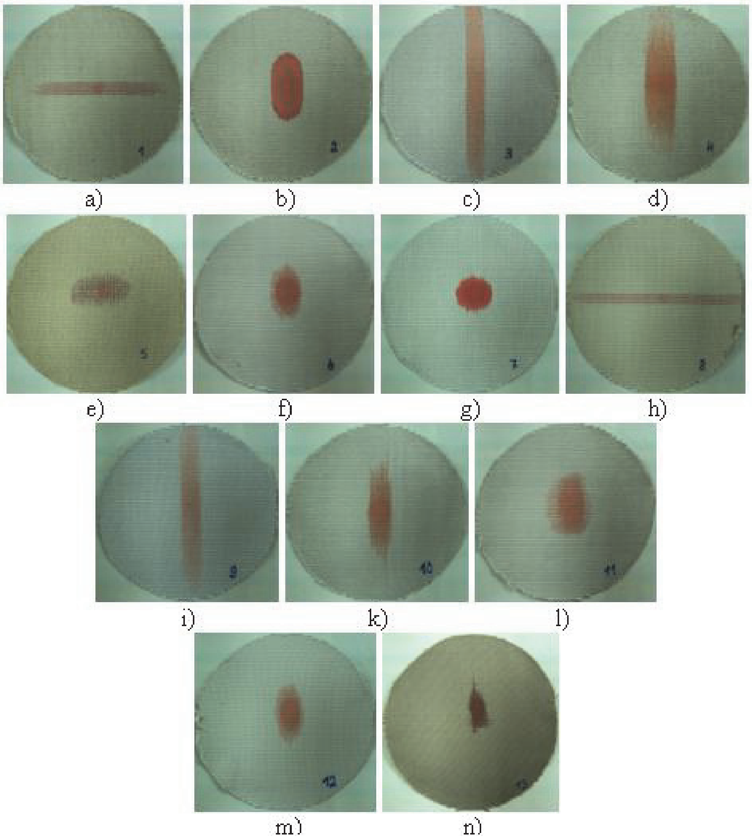


Figure 5. Results of drop test (after 5 minutes) a) N1, b)N2, c)N3, d)N4, e)N5, f)N6, g)N7, h)N8, i)N9, k)N10, l)N11, m)N12, n)NIF

During the drop test not only the rate of absorption, but also the tendency of liquid spread along the wale and course direction was assessed. Table 2 shows this evaluation. Rating is done on a 1 to 5 scale with 1 being the lowest and 5 the highest rating.

According to data the samples with channeled polyester fibers (N3, N9, and N10) had the highest absorption rates. This can be attributed to capillary effect caused by the channels. Capillarity is the movement of liquid along the surface of a solid caused by the attraction of molecules of the liquid to the molecules of the solid. In other words, diffusion of liquid from high concentration to low concentration [39]. Physically capillary action occurs when liquid molecules attract the molecules of the fiber. The extent of liquid propagation is influenced by the closeness of solid walls generated by textile material [40]. Channeled fibers have greater surface area compared to circular fibers. As a result, they provide smaller voids per unit area. Sample N8 gave the lowest absorption rate. This sample contains plied cotton yarn. Similarly all samples with cotton content had low absorption. In these samples liquid spread along the Wales direction.

3.3. Porosity

Porosity mainly depends on yarn density, yarn diameter, yarn twist and fiber diameter. Porosity of bandage samples is presented in Figure 6. The ANOVA test confirmed that there was a statistically significant difference between the porosity values of bandage samples. Like in air permeability, coarser weft yarns resulted in low porosity. The highest surface porosity was given by samples NIF, N10 and N11. These samples also had low fabric densities. Fiber type did not have a significant effect on the porosity values of bandage samples. It appears that yarn density had a predominant effect on porosity. Similar to air permeability sample N6 had low porosity, even though it had low density. Porosity has a significant effect on air permeability, as well [37]. As expected, air permeability of bandage samples was proportional to their porosity (Figure 7).

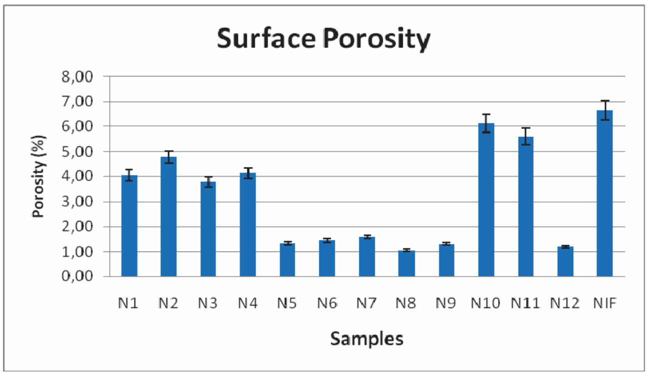


Figure 6. Surface porosity of bandages

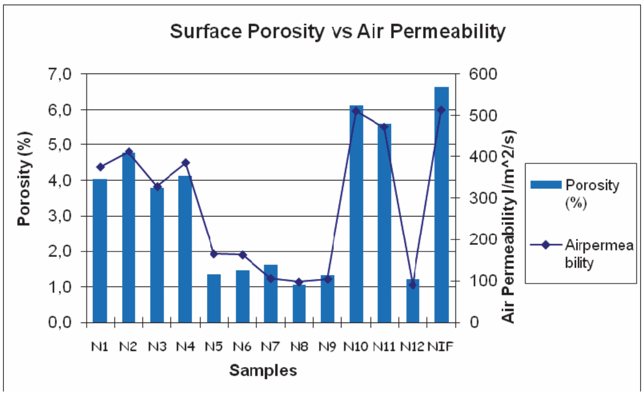


Figure 7. Relationship between surface porosity and air permeability

Table 2. Characteristics of water spread

Sample	Rate of absorption	Spread direction	Wales (*y*)	Courses (*x*)	Wale/Course %	Shape of spread
N1	2	Wales	10,5	1,0	10%	Column-like
N2	4	Course + Wales	2,8	5,8	48%	Elliptical
N3	5	Course	1,7	14,2	12%	Column-like
N4	4	Course	2,8	10,0	28%	Column-like
N5	2	Wales + Course	5,0	2,7	54%	Elliptical
N6	4	Course + Wales	2,8	4,4	64%	Elliptical
N7	3	Wales + Course	3,1	2,9	94%	Circular
N8	1	Course	14,4	0,8	6%	Column-like
N9	5	Course	1,8	12,5	14%	Column-like
N10	5	Course	2,1	7,5	28%	Column-like
N11	4	Course + Wales	3,9	5,0	78%	Circular
N12	3	Course + Wales	2,5	4,9	51%	Elliptical
NIF	4	Course + Wales	1,5	3,3	45%	Elliptical

3.4. Thermal Comfort

Thermal comfort characteristics of bandages were evaluated through thermal conductivity, thermal absorbtivity and thermal resistance tests. The result of one-way ANOVA test revealed significant differences among the thermal conductivity, thermal absorptivity and thermal resistance values of bandage samples produced from different type of weft yarns. Figure 8 illustrates the thermal conductivity of bandage samples. High thermal conductivity means that the generated excess heat will be removed from body in a faster rate it will reduce the sweating and therefore the wearer will feel more comfortable. According to data the highest thermal conductivity was provided by sample N8, which contains plied cotton yarn. The other important finding was that all the samples with plied yarns (N12, N5 and N7) had higher thermal conductivity values. Since these fabrics had higher densities they had less air trapped inside fabric structure. Still air has very low conductivity compared to fiber material. The effect of fabric weight was not evident. Apparently, the effect of yarn structure and fiber type on thermal conductivity of bandages suppressed the effect of fabric weight.

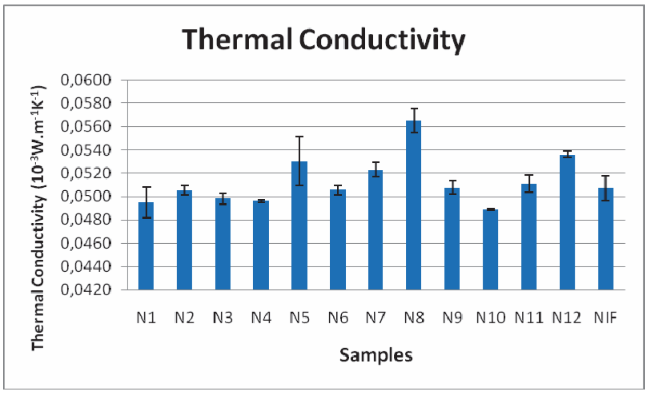


Figure 8. Thermal conductivity of bandages

Thermal absorbtivity is related to “warm-cool” feeling of fabrics at first touch. If thermal absorbtivity is high, fabric gives a cooler feeling at first contact. The thermal absorbtivity values of samples were given in Figure 9. The highest absorbtivity was given by sample N7, containing plied viscose yarn, and sample N8, including plied cotton yarn. These bandage samples gave high thermal conductivity values, too. This could be attributed to high fabric density which caused by closely arranged fibers in these fabrics.

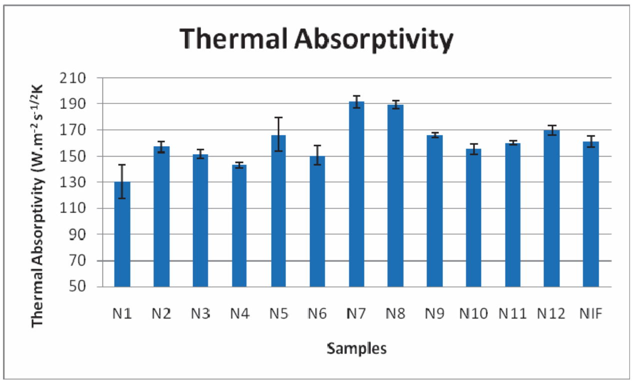


Figure 9. Thermal absorbtivity of bandages

Thermal resistance is an important parameter which influences the isolation property of fabric. It is directly proportional to fabric thickness and inversely proportional to thermal conductivity. Figure 10 shows thermal resistance of samples. For the first four samples which produced from the yarns with the same count, as the fabric thickness increased the thermal resistance of bandages also increased. The thinnest bandage sample (NIF) caused to the lowest thermal resistance. This result is consistent with previous researches which demonstrates that there is a positive correlation between fabric thickness and thermal resistance of fabrics [41, 42]. The effect of fiber type was more noticeable with bandage samples produced from plied yarns and filament yarns. Channeled polyester spun yarn (sample N9) and filament yarn (sample 10) caused higher thermal resistance compared to cotton (sample N8) and regular polyester yarn (sample 11), respectively. Evidently, the air captured inside the channels improved the thermal resistance.

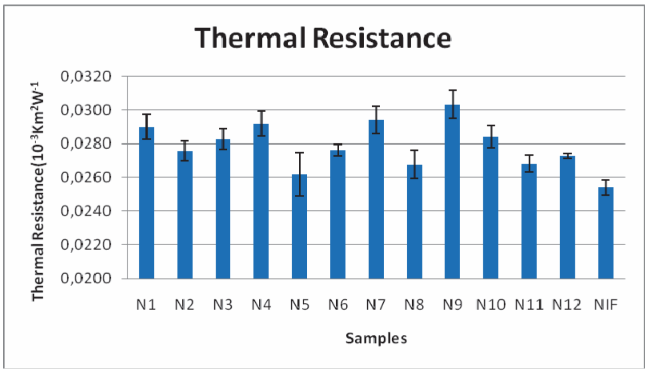


Figure 10. Thermal resistance of bandages

3.5. Bandage samples with PCM microcapsules

SEM analysis

SEM images of bandages with PCM microcapsules are given in Figure 11. Silk fibroin/Chitosan microcapsules clearly seen in the images. These SEM images verifies that PCM microcapsules were successfully incorporated into fabric structure.

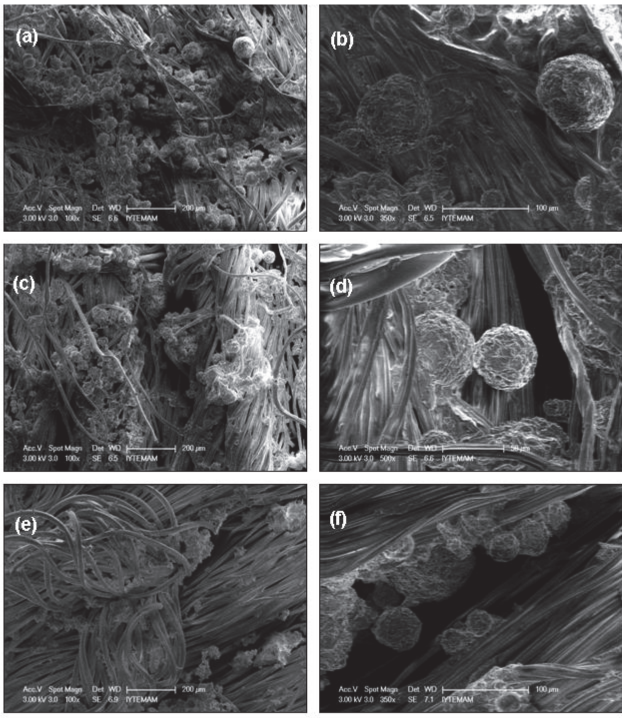


Figure 11. Bandage samples with microPCMs - a) sample N1 (100x); b) sample N1 (350x); c) sample N3 (100x); d) sample N3 (350x); e) sample N10 (100x); f) sample N10 (350x)

Thermal Properties of microPCM containing bandages

The effectiveness of microcapsules was tested on Alambeta instrument. Table 3 shows the results for the elastic bandage made from 5 channeled polyester fibers.

Micro PCM containing bandages had lower thermal conductivity, and high thermal absorbtivity and thermal resistance compared to regular bandages, but the differences were very small. It is likely that some of heat applied to bandage was absorbed by the phase change material inside the capsules. However, the real effect was not detectable due to the test conditions. Alambeta Instrument measure and evaluate the heat transfer through a fabric placed between two plates at 32 °C and 22 °C, respectively. At elevated test temperatures the effect of n-eicosane (PCM) would be more detectable since its melting point is around 36°C. Further investigations with appropriate test methods should be conducted to reveal the clear effect of PCM microcapsules.

Table 3. Thermal Comfort properties of microPCM containing bandages

Sample No	**Sample Content**	**Thermal conductivity ($Wm^{-1}K^{-1}$)**	**Thermal absorbtivity ($Wm^{-2}s^{-1/2}K$)**	**Thermal resistance (Km^2W^{-1})**
N10	Regular bandage	0.522	158.2	0.025
N10-PCM	Bandage with PCM microcapsules	0.517	160.6	0.028

4. CONCLUSION

Comfort provided by elastic bandages during usage in daily life or extreme conditions is as important as clothing comfort. Comfort properties of elastic bandages can be improved by utilizing some special fibers and functional components. In this study, elastic bandages were produced from different materials and their air permeability, surface porosity, water absorbency and thermal comfort properties were compared. In addition, PCM loaded silk fibroin/ chitosan microcapsules were applied to some bandages to improve their comfort properties. It appears that air permeability depended on fabric density and surface porosity. Capillarity played a significant role in water absorbency. Particularly, channeled fiber structure improved water absorbency in a great extent. Thermal conductivity was affected by fiber type and fabric density. Cotton and viscose fibers and dense fabric structure caused high thermal conductivity. Thermal resistance showed an opposite trend. The effect of PCM microcapsules on the thermal comfort properties of bandages was not clearly detected due the shortcomings of the test method. Additional studies with appropriate methods are needed to fully explore the real effect.

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REFERENCES

1. Mecit D., Ilgaz S., Duran D. et. al., 2007, “Technical textiles and applications (part 1)”, *Tekstil Ve Konfeksiyon*, 17 (2), p: 79-82.
2. http://medical-dictionary.thefreedictionary.com (Accessed on 06.07.2015)
3. Simmers L.M., 2008, Diversified Health Occupations, Cengage Delmar Learning, p: 520
4. Günay, S., 1999, 2. Derece Ayak Bileği Burkulması Geçiren Sporcularda Elastik Bandaj ve Air-cast Brace Kullanımının Motor Performans Üzerine Etkisi, Bilim Uzmanlığı Tezi, Hacettepe Üniversitesi Sağlık Bilimleri Enstitüsü, Ankara, s:64.
5. Rigby, A.J. and Anand, S.C., 2003, Medical textiles, Handbook of Technical Textiles, Horrocks, A.R. and Anand S.C. (Eds.), Woodhead Publishing Ltd., Cambridge-England, p: 407-424
6. Ilgaz, S., Duran, D., Mecit, D. et al, 2007, “Medikal tekstiller”, *Tekstil & Teknik*, 23(265), p:138-162.
7. Spencer, D.J., 2001, Knitting Technology – A Comprehensive Handbook and Practical Guide, Woodhead Publishing Ltd., Cambridge-England, p: 386
8. Mazza, Z. and Zonda, P., 2002, Reference Books of Textile Technologies – Knitting, ACIMIT Foundation, Italy, p:117
9. Andreen, J. H., Gibson, J. W., and Wetmore, O. L., 1953, “Fabric Evaluations Based on Physiological Measurements of Comfort”, Textile Res. J. 23, p:11–22.
10. Gagge, A. P. and Gonzalez, R. R., 1974, Physiological and Physical Factors Associated with Warm Discomfort and Sedentary Man, Environ. Res. 7, p:230 .
11. Goldman, R. F., Evaluating the Effect of Clothing on the Wearer, 1981, Bioengineering, Thermal Physiology and Comfort, Cena, K. and Clark, J. A., Eds., Elsevier Scientific Publishing Co., Chap. 3, Amsterdam.
12. Adler, M. M., and Walsh, W. K., 1984, “Mechanisms of Transient Moisture Transport Between Fabrics”, Textile Res. J. 54, p:334–343.
13. Pontrelli, G.J., 1990, “Comfort by design”, Textile Asia, 21(1), p:52–61.
14. Mehta, R., Narrasinham, K.V., 1987, “Clothing comfort – A review of related properties”, Man-made Textile in India, 30, pp. 327-35.
15. Hatch, K. L., Woo, S. S., Barker, R. L., Radhakrishnaiah, P., Markee, N.L. and Maibach, H.I., 1990, “In Vivo Cutaneous and Perceived Comfort Response to Fabric Part I: Thermophysiological Comfort Determinations for Three Experimental Knit Fabrics”, Textile Res. J. 60, 405–412.

16. Barker, R.L., Radhakrishnaiah, P., Woo, S.S., Hatch, K.L., Markee, N.L., Maibach, H.I., 1990, “In vivo cutaneous and perceived comfort response to fabric, Part II: mechanical and surface related comfort property determinates for three experimental knit fabrics”, Textile Res. J. 60, 490-494.

17. Yick, K. L.. Cheng. K. P. S., and How. Y. L., 1995, “Subjective and Objective Evaluation of Men’s Shirting Fabrics”, Int. J. Cloth. Sci. Technol. 7 (4), p:17-29.

18. Tarafdar, N., 1995,“Selection of appropriate clothing in relation to garment comfort”, Man-made Textiles in India, 38 No. 1, pp. 17-21.

19. Shim H., McCullough E.A., 2001, “Using phase change materials in clothing”, Textile Research Journal, 71, p:495-502.

20. Zhang X.X., 2001, Heat-storage and thermo-regulated textiles and clothing. In: X.M. Tao (ed) Smart fibres, fabrics and clothing, CRC Press, Boca Raton, FL, p: 34-57.

21. Ying B., Kwok Y.L., Li Y., et al., 2004, “Thermal regulating functional performance of PCM garments”, *International Journal of Clothing Science and Technology* 16, p:84-96.

22. Ying B., Kwok Y.L., Li Y., et al., 2004, “Assessing the performance of textiles incorporating phase change materials”, *Polymer Testing* , 23, p:541–549.

23. Thakare A.M., Sangwan A., Yadav S., 2005, “Providing comfort through phase change materials.”, *Man Made Textiles in India* 48, p: 239–242.

24. Sarier N., Onder E., 2007 “The manufacture of microencapsulated phase change materials suitable for the design of thermally enhanced fabrics.”, *Thermochim. Acta* 452, p:149-160.

25. Onder E., Sarier N., Cimen E, 2007, “Encapsulation of phase change materials by complex coacervation to improve thermal performances of woven fabrics”, *Thermochimica Acta* , 467, p:63-72.

26. Mondal S., 2008, “Phase change materials for smart textiles - An overview.”, *Applied Thermal Engineering*, 28, p:1536-1550

27. Mattilla H., 2006 , Intelligent Textiles and Clotting, Woodhead Publishing Limited, Cambridge, p:29.

28. Pan N., Sun. G., 2011, Functional Textiles for Improved Performance, Protection and Health, Woodhead Publishing Limited, Cambridge, p:177.

29. Bartels, V. T. ,2011, Handbook of Medical Textiles, Woodhead Publishing Limited, Cambridge, p:205-212.

30. Song, G., 2011, Improving Comfort in Clothing Woodhead Publishing Limited, Cambridge, p: 370-381.

31. Gokarneshan, N., Anitha Rachel, D., Rajendran, V., Lavanya, B., Ghoshal, A., 2015, Emerging Research Trends in Medical Textiles, Springer Science + Business Media Singapore Pte Ltd., p:100-117.

32. Oğlakcıoğlu, N., Marmaralı, A., 2010, “'Rejenere Selüloz Liflerinin Kompresyon Çoraplarının Isıl Konfor Özelliklerine Etkisi”, Tekstil ve Mühendis, Yıl:17, Sayı:77, 6-12

33. Deveci, S. S., Basal, G., 2009, “Preparation of PCM microcapsules by complex coacervation of silk fibroin and chitosan”, *Colloid & Polymer Science*, 287 (12), p:1455-1467.

34. Arıkan, C.O., 2008, Bilgisayarlı Resim İşleme Uygulamalarının Tekstilde Kullanılması Üzerine Bir Araştırma, Doktora Tezi, Ege Üniversitesi Fen Bilimleri Enstitüsü Tekstil Mühendisliği Anabilim dalı, İzmir, 128s .

35. Hes, L., Dolezal, I., 1989, “New method and equipment for measuring thermal properties of textiles”, *J. Text. Mach. Soc. Jpn.,* 42 (8), p:124-128 .

36. Hes, L., Hanzl, J, Dolezal, I., Miklas, Z., 1990, "New method and instrument for the objective evaluation of thermal-contact properties of flat textile fabrics", *Melliand Textilberichte*, 71, p: 679-81.

37. Wilbik-Hałgas, B., Danych, R., Więcek, B. and Kowalski, K., 2006, “Air and water vapour permeability in double-layered knitted fabrics with different raw materials”, *Fibres & Textiles in Eastern Europe*, 14(3), p:77-80.

38. Rouette H.K., 2001, Encyclopedia of Textile Finishing, Springer, Germany, p: 2765

39. Gerhart P.M., Gross, R.J., Hochstein J.I., 1992, Fundamentals of fluid mechanics, Addison Wesley, p 21.

40. Wiener, J. and Dejlova, P., 2003, “Wicking and wetting in textiles”, *AUTEX Research Journal*, 3(2), p:64-71.

41. Wei J., Xu S., Liu H., Zheng L., Qian Y. 2015, “Simplified Model for Predicting Fabric Thermal Resistance According to its Microstructural Parameters”, FIBRES & TEXTILES in Eastern Europe, 23, 4(112), p: 57-60.

42. Oglakcioglu N., Celik P, Bedez Ute T, Marmarali A, Kadoglu H, 2009,'Thermal Comfort Properties of Angora Rabbit/Cotton Fiber Blended Knitted Fabrics', Textile Research Journal, 79(10), p:888-894