Thermographic Assessment of Bio-based Materials for Functional and Sustainable End Product

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Abstract

The low biodegradability of synthetic fibers is becoming an increasing concern for sustainability issues. Lately, bio-based materials have attracted remarkable attention, due to their independence of petroleum, as well as eco-friendliness and recyclability. It is estimated that by the end of 2020, the global market of bio-based materials will reach $250 billion, and ten years later, almost one-third of all materials and chemicals will be sourced from biological ingredients. Recently, scientists have given significant effort to improve the degradability of the synthetic fibers and to develop bio-based materials from different renewable resources. Their research is directed towards three main groups of material defined according to the sources: (i) synthetic polymers from natural monomers, including polylactide acid, (ii) polymers from bacterial fermentation, like polyhydroxybutyrate and (iii) natural polymers such as cellulose, protein and starch. The outcomes of published investigations confirmed great potential of bio-based materials in both conventional durable goods and disposable goods. Still, the scientist point out that the use of bio-based materials is limited, mainly due to unsatisfactory or under-researched functionality of end product (primary referring to thermal and mechanical properties). This presentation gives a comprehensive, multi-scale approach for the evaluation of bio-based material functionality by means of thermography, under different simulated thermal environments. The results of measurements confirmed that investigated bio-based materials exhibit great potential for use regarding optimal thermal characteristics, what gives additional incentive to continue the development of bio-based materials and promote their use.

Keywords: thermography, bio-based, materials, functionality, cellulose yarn, apparel

1. Introduction

Over the years, the low biodegradability of synthetic fibers used for a wide range of applications, is becoming an increasing concern for a number of sustainability issues. In the recent years, bio-based materials have attracted remarkable attention of scientists and industrials, due to their independence of petroleum, as well as eco-friendliness and recyclability. Experts in the field estimate that by the end of 2020, the global market of bio-based materials will reach $250 billion. It is expected that ten years later, almost one-third of all materials and chemicals will be sourced from biological ingredients. Recently, scientists have given significant effort to improve the degradability of the synthetic fibers and to develop bio-based materials from different renewable resources. Their research is directed towards three main groups of material defined according to the sources:

(i) synthetic polymers from natural monomers, including polylactide acid (PLA),

(ii) (ii) polymers from bacterial fermentation, like polyhydroxybutyrate (PHB) and

(iii) natural polymers such as cellulose, protein and starch.

The outcomes of published investigations confirmed great potential of bio-based materials in both conventional durable goods and disposable goods. Still, the scientist point out that the use of bio-based materials is limited, mainly due to unsatisfactory or under-researched functionality of end product (primary referring to thermal and mechanical properties). The published comparative study of materials made from bio-based polylactide acid/poly (hydroxybutyrate-co-hydroxyvalerate) (PLA/PHBV), Cupro, polyethylene terephthalate (PET) and polyamide 6 (PA 6) multi-filament yarns, indicated that PLA/PHBV has adequate thermal properties (regarding the Qmax value) and lowest Young's modulus (only 44.02 cN/tex) among compared materials (Zhang et al., 2017; Huang et al., 2017).

2. Infrared thermography

Infrared thermography is a non-destructive measuring method for the determination of temperature distribution on the surface of objects. The camera receives radiation from the target object, plus radiation from its surroundings that has been reflected onto the object's surface. Given this situation, the calculation of the object's temperature from a calibrated camera's output is derived from: emission from the object, reflected emission from ambient sources and emission from the atmosphere. These components form the total radiation power received by the camera that can further be written as:

$$W_{tot} = \varepsilon \cdot \tau \cdot W_{obj} + (1-\varepsilon) \cdot \tau \cdot W_{amb} + (1-\tau) \cdot W_{atm} \quad (1)$$

Nowadays, thermography is very popular among the researchers in various fields. It can be used to observe the production process, material properties, failure, product development and much more (Fournet et al., 2013; Roberts et al. 2007; Merla et al. 2010). The researchers confirmed that thermography is a great tool to assess the efficiency of the material intervention and has great potential for evaluation of regional or whole patterns for targeted product (Fournet 2013; Fournet et al., 2012; Fournet et al. 2013; Matusiak 2010; Salopek Čubrić et al. 2009).

Up to now, the main research interest of authors of this paper was focused towards thermographic investigation of different polymer materials with main purpose to evaluate functionality of material under different conditions (Salopek Čubrić et al., 2016a; Salopek Čubrić et al. 2016b; Čubrić et al. 2013) as well as inclusion of human factor to define the impact (Salopek Čubrić et al., 2019).

In the focus of the research presented in this paper is the functionality of bio-based material produced of cellulose with regards to thermal properties, as well as potential for the use.

3. Functionality of Bio-based materials

The functionality of bio-based material is throughout this paper observed by means of thermography. The main goal is to investigate thermal properties of bio-based material and its suitability to be functional if worn as an apparel product. For the investigation is prepared bio-based material. Microscopic images of bio-based material (both upper and lower surface) are given in the Figure 1. The main characteristics of bio-based material used in this study are presented in the Table 1.

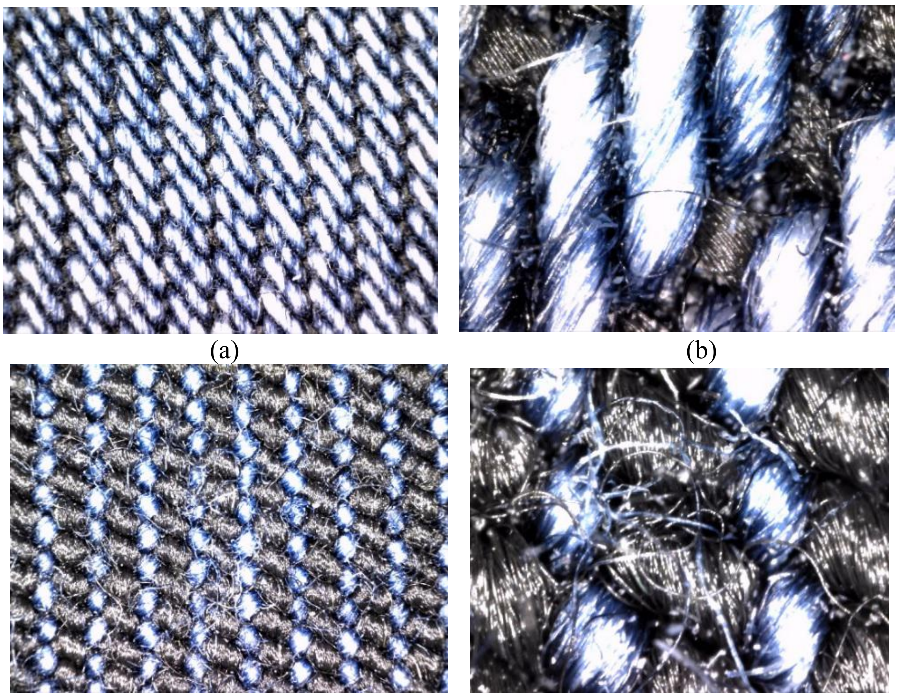


Fig.1 Structure of used bio-based material (a) upper surface taken under magnification of 50x, (b) upper surface under magnification 200x, (c) lower surface surface taken under magnification of 50x, (d) lower surface taken under magnification of 200x

Table 1 Bio-based material properties

Raw material	98% cellulose (cotton) + 2% elastane
Cellulose fibre fineness, dtex	1.9
Elastane yarn fineness, dtex	44
Cellulose yarn fineness, tex	20.11
Material mass, g/m^2	560.20
Material thickness, mm	0.75

For the purpose of the experiment, bio-based material is shaped into trousers in two different modifications allowing different air circulation between the skin and material. In further text, the two modifications are assigned as:

- AC-high – corresponds to the looser model that enables higher circulation of air between skin and material.
- AC-low – corresponds to the tighter model that enables lower circulation of air between skin and material.

The functionality of bio-based material in preservation of optimal level of thermal comfort is investigated trough the measurement of temperature on the upper surface of bio-based material with thermal camera. The measurement is conducted using the thermal camera FLIR E6 (Salopek Čubrić et al., 2016) with thermal sensitivity <0.10°C. In the experiment participated both male and female subjects. The experiment is approved by Ethical Committee of the University of Zagreb, Faculty of Textile Technology, on May 05, 2019. The Committee confirmed that proposed research is in accordance with research ethics, Code of Ethics of Croatian Science Foundation and the Code of Ethics of the Ethics Committee in Science and Higher Education.

The participation of male and female subjects is in further text assigned as follows: P:M (for the participation of male subject) and P:F (for the participation of female subject). The changes of bio-based material temperature due to previously defined influencing factors are observed for the following zones of body: pelvis (P), upper thigh (UT), lower thigh (LT), knees (K), upper shin (US) and lower shin (LS).

In order to observe the functionality of bio-based material under different temperatures, two additional cases are defined:

- Case 1: measurements are carried out in the chamber with average air temperature of 20±0.2 °C and
- Case 2: measurements are carried out in the chamber with average air temperature of 10±0.2 °C.

In the second stage of the experiment, the analysis of thermograms taken under all of above defined conditions is completed. All the data obtained in the experimental part are analysed using the Flir Tools Software.

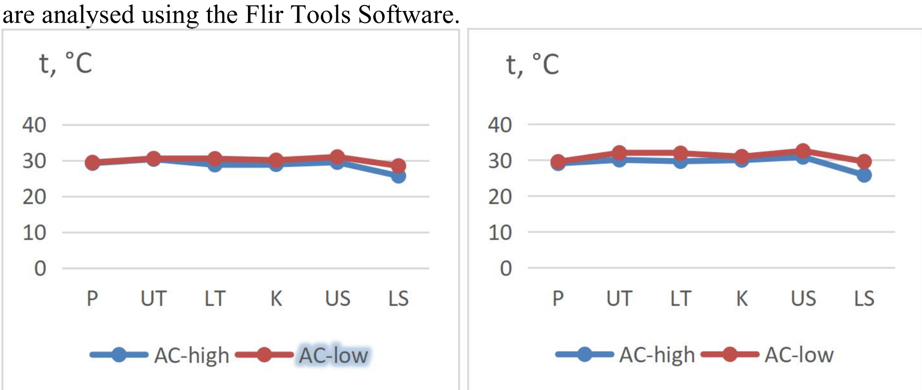
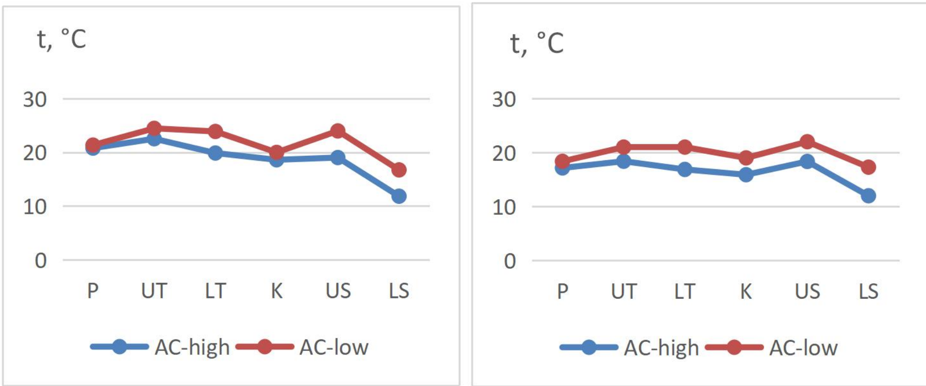


Fig. 2 Average temperatures measured on the surface of bio-based material for the Case 1: (a) P:F, (b) P:M



a. b.

Fig. 3 Average temperatures measured on the surface of bio-based material for the Case 2: (a) P:F, (b) P:M

The results presented in the Figure 2 refer to average temperature of the surface of bio-based material for the Case 1 (i.e. measured in chamber with average air temperature of 20±0.2 °C). As can be seen from the figure, there is a high level of compliance regarding the temperatures of bio-based material for observed zones under both AC-high and AC-low. Differences of temperature are seen for the LS zone only, what should be explained by additional circulation of the ambient air in the lowest observed zone.

The outcomes are quite different for the Case II. As can be seen from the Figure 3, the temperatures on the surface of bio-based material are significantly different for the AC-high and AC-low. The differences are most prominent for the zones LT, US and LS.

The discussed results are compared to previously published results of authors of this paper that were focused towards thermographic investigation of conventional materials.

The comparison indicated that trends of temperatures on bio-based material follow the trends of conventional material. Moreover, the differences in temperatures of bio-based material regarding the observed influencing factors are even lower than measured for conventional material. This leads to the conclusion that bio-based material have strong potential for further use.

4. Conclusions

In this paper is presented a comprehensive, multi-scale approach for the evaluation of bio-based material functionality by means of thermography, under different influencing factors. The results of measurements confirmed that investigated bio-based material exhibits great potential for use regarding optimal thermal characteristics, what gives additional incentive to continue the development of bio-based materials and promote their use.

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