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Mechanical, sound absorption and thermal properties of cork fabric

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This study focuses on two different kinds of cork leathers that are environment friendly and represent as an important sustainable alternative to leather. The general properties of cork leather have been investigated in this study to highlight their potential use as coated-textile structures. The potential use of cork fabrics as technical textiles is also discussed to promote the use of technical textiles, such as buildtech and automotive textiles. The sound absorption and thermal properties of the cork structures are tested and compared with those of reference lamb leather. It is found that the developed cork-based structures have promising mechanical, thermal, and sound absorption properties for further application.

Keywords: Cork fabric, *Quercus suber L*, Mechanical properties, Sound absorption, Thermal properties, Vegan leather

1 Introduction

The leather industry is one of the biggest polluters, and hence the studies are being conducted to produce new leathers that are more sustainable and environment friendly to maintain the ecological balance. Animal-free leather, also known as the concept of vegan or alternative leather, is attracting a lot of interest as a part of the ongoing trend of “Sustainable Product Design". This concept is being advanced in a number of ways, including coatings made from recycled waste materials and natural-based byproducts. As a promising result of these studies, new perspectives for vegan leather are emerging. One of the most studied vegan textile coating materials is mycelium. The literature discusses that the use of mycelium has great potential, but the main problem to be solved is the complexity of harvesting, processing, and application possibilities at an industrial scale[1]. The method aims to obtain synthetic component coatings to reduce the non-renewable content of artificial leather with natural ingredients, such as apple pomace (Vegea, Appleskin) or cactus leaves (Desserto)[2].

Another important natural material, cork, is used in the development of vegan leather. Cork, which belongs to the fungal species, is obtained from the outer bark of the genus *Quercus suber* L, a characteristic tree of the western Mediterranean region[3]. The countries where the cork oak is naturally distributed are Spain, Portugal, Italy, Morocco, Algeria, Tunisia, and France[4-6]. Most of the world’s cork production takes place in Portugal[6,7]. During cork harvesting, the cork tree is not cut down and it has the ability to replenish itself. These two factors make the process eco-friendly and sustainable[8,9]. It stands out as a renewable and reusable raw material. It is reasonably impermeable to gases and liquids, an electrical or thermal insulator, and have the ability to absorb vibrations[9]. It is used in various fields such as medicine and construction, especially for bottle caps in the beverage industry[10]. Its unique properties, such as lightweight, soft, and flexibility, make it appropriate to be used in different fields, such as fabric and leather. In recent years, cork leather has put-to-use in different sectors, such as furniture, clothing, footwear, and accessories. The most important sector for cork products is cork stoppers in the wine industry which represent about 69% of the total cork industry[9]. Due to its cellular structure, cork skin is very light and elastic[11].

One of the crucial characteristics of cork production is its negative footprint[9]. The carbon harvested in cork represents less than 1.5% of annual net primary production. There are several ways to acknowledge that a material is environment friendly. The rate of carbon emission into the environment and rate of water consumption is remarkable among those. It is also important to mention that the water consumption during the growth of the cork oak is negligible. It is commonly known that the Green Deal

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is the main objective of recent sustainable materials and industrial processing. The investigations before and after the cork production include Life Cycle Assessment (LCA), which is positively evaluated in different studies for a number of sectoral applications of the cork material[12]. It is clearly mentioned that the production of raw cork does not have negative effect to environment as it does not need any chemical during growing. The process of extracting cork leather begins with the removal of the bark from the cork oak. As shown in Fig. 1, it can be easily peeled off from the tree in the form of semi-tubular pieces through the separation process from the phthalogen layer[13]. This peeling process can occur in late spring and early summer when the tree is physiologically active[14]. As the cells swell and are thin at this time, they can be torn off without damaging the lower tissues[15]. This process is repeated after each fungal attack. There are different stages of uncorking that enable to manufacture corks of different quality and with different external surfaces. The earliest uncorking produces virgin cork, which has a very uneven outer surface while reproductive cork or *Amadiahasa* shows uniform outer surface after uncorking[16].

The cross-section of a cork cell consists of 5 layers that are not uniformly formed (Fig. 1). Two of these layers are composed of cellulose surrounded by air-filled cellular chambers[17]. These air-filled spaces are called intercellular layers, and their structure has a great influence on the strength and flexibility of the materials. Suberin and waxes form the next two layers that give cork a hard and water-repellent character. The last layer is woody and is responsible for the structure and necessary strength of a cell[18].

Cork has a 14-sided cell structure. Due to the air contained in the cell, it provides good thermal and sound insulation. In a 1 cm piece of mushroom, there are about 40,000,000 cells filled with air[19,20]. Due to this property of cork, no matter how much pressure is applied, 95% of it returns to its original size when the pressure is removed[21].

After harvesting, the cork sheets are stacked in the forest or in the yard of the factories where they are processed. In this process, they are exposed to the sun, wind, and rain. Exposure to rain, sun, and wind results in chemical transformations that increase the quality of the fungus[7]. This phase is called the stabilization phase, where unwanted tannins are broken down and the water content is lowered. The cork plates are immersed in clean boiling water and kept in water bath at 100 °C for about 1 h[22]. Strong alkalis, nitrous acids, and oxidizing halogens are used for the water content[23]. The purpose of this process is to clean the cork plates, remove the dust and bacteria, soften and flatten the shell, reduce the density by increasing the thickness and to increase flexibility. After boiling, the cork plates are allowed to rest for 2 or 3 weeks. Cork panels are sorted and sliced according to the requirements of different applications[10]. Cork leather or fabric-reinforced cork structures are developed and manufactured from very thin cork veneer and various backing materials[24]. To produce the cork leather, the middle layer of the cork is cut about 1.5 cm thick with sharp knives. These thin cork sheets are laminated to the fabric backing using organic adhesives and a special proprietary technique to create larger pieces like patchwork. Fabric types vary depending on the desired weight and functionality. Usually, cotton and polyester are used as substrates.

Just like textile products based on natural raw materials, the cultivation process is influenced by soil and environmental conditions, and if these differences are observed in the final yarn properties, the quality of cork is influenced by environmental conditions according to the growth conditions of the fungus. The cork quality can also be reflected in different observable values in the cork leather obtained as a final product[25].

This study aims to discuss two different textile reinforced cork structures and the lamb leather as reference structure. After conducting general

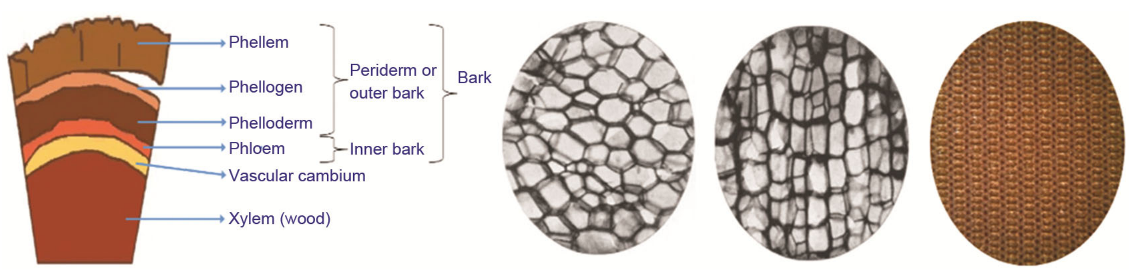


Fig. 1 — Cross-section of cork bark and laminated knitted backing layer

academic research on cork reinforced (laminated) fabrics, it is clearly seen that there is a need for such investigation to highlight the main mechanical properties of such sustainable structures. It is also important to mention that there is a need to highlight such vegan leathers' technical properties to demonstrate innovative applications.

2 Materials and Methods

Two different textile structures (nonwoven and knitted), used as the backing of the cork leathers, and the reference lamb leathers were kindly provided by a German company named Korkstoffe. The cork reinforced structures were used as received (Fig. 2). The cork-based structure, which is known by different names, such as "cork leather" and "cork textile or cork fabric", is basically obtained by coating the textile structure by cork skin. In general, there is no need to use water, pesticides and fertilizers while the tree is growing. The cork skin, which is formed into a layer of 0.3 – 0.4 mm in accordance with textile coatings, is attached to the textile surface with different types of adhesive resin. In this study, synthetic textile structures were used as the back surface, but it is recommended that the textile structure and adhesive should be biobased structures for a 100% sustainable material. Commercially available cork leather was used in this study and the main goal was to describe the structure and draw attention to its general characteristics.

All test parameters were applied at the standard test atmospheric temperature of 20 ± 2 °C and relative humidity of 65 ± 4 %. The test methods are explained hereunder and the results are interpreted accordingly. The area density values of the tested samples have been determined in accordance with the ASTM D 3776 standard and the thickness is determined in accordance with the TS EN ISO 9073-2 standard by making use of a Mitutoyo thickness measuring micrometer. The tensile properties were determined by using an Instron Universal Tensile Tester (Model-5567) following the standard test method TS EN ISO 13934-2. The tear strength of the leathers is measured using James Heal, Elma Tear Equipment in accordance with EN ISO 13937-1 2000 - Part 1: Ballistic Pendulum Method (Elmendorf). The air permeability test has been performed in accordance with the standard TS 391 ISO 9237. The contact angle test has been performed in accordance with ASTM C813-90. The solution used in the test is water. The color fastness test is performed to observe the color properties of fabrics during use. The goal is to ensure that the fabric does not discolor and fade over the time, as is observed in this study. Textile color fastness test (TS 396 EN ISO 105-E01) has been applied to evaluate the color changes of the cork structures and to determine their suitability for outdoor use.

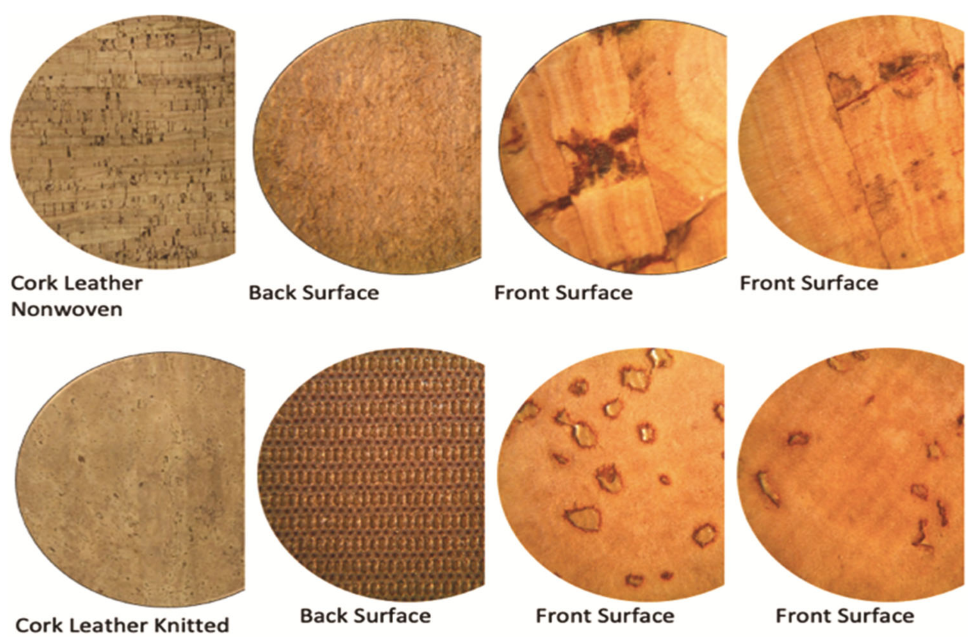


Fig. 2 — Cork leather samples

3 Results and Discussion

3.1 Thickness and Area Density of Structures

The area density values of the tested samples show that the nonwoven reinforced cork leather has a significantly thicker structure as compared to the knitted counterpart. This is due to the bulky nature of the nonwoven structure. On the other hand, it is found that the areal density of the nonwoven reinforced samples has a very low value (Table 1). As mentioned above, as the thickness of the cork skin is adjusted, the textile backing layer can also be adjusted to desired thickness, depending on the usage area.

3.2 Mechanical Properties

The mechanical properties of such coated or laminated structures are crucial for further processing line as well as the customer acceptance. The formability and structural stability of such developed leathers during use are important There are some different types of novel exotic leathers that are tried to be applied as fast fashion items; however, these structures have limited use as they do not provide mentioned main features. While comparing the reference lamb skins and the textile-reinforced cork leathers used in the study, it is found that the maximum force (tensile strength) can be increased up to the desired ratio, depending on the backing structure (reinforcement fabric). It varies depending on the structural properties of the reinforcing fabric and the degree of adhesion to the cork used as a coating. In conventional textile products, woven fabrics are more durable than nonwoven textile structures, which consist of a random distribution of fibres, with the yarns adhering to each other. It is also important to mention that the cork coating itself does not have any direct effect on tensile strength, as they are attached with small pieces. The mechanical properties of cork coated fabric can be equivalent or increased to those of the natural leathers, as it depends on the backing textile structures. Cork is a viscoelastic- material It allows large deformations without breaking under pressure and offers a significant dimensional improvement when the stress is relieved[26,27]. The structural design advantage is better than in conventional leather. As can be seen in Table 2, the strength of both textile-reinforced cork leathers is higher than that of lamb leather; despite having the thinnest structure, they provide the highest values of strength. This test shows no disadvantage of cork in terms of mechanical use, in general. However, the effect of the knitted fabric and the cork structure should be studied in more detail here for the same strength level. The general properties of the functional organic binder that binds the cork and fabric structure are crucial to make 100% vegan leather. It is an animal-free binder that is developed by the company. The detailed features of the binder used are not shared for privacy reasons. The cork structure, in this study, breaks simultaneously with the fabric structure. This prevents the formation of equal force. The backing fabric' tensile properties have to be enhanced, as cork skin has higher tensile properties which causes different break point. This shows that the strength of cork is high Since the specially knitted fabric has multidirectional strength, the cork resembles a similar multidirectional structure. The microscopic images of cork and knitted reinforcement show structural similarity[28]. Therefore, the samples reinforced with cork show better opacity and strength properties. Although there is no example in the literature, there are commercial products made out of cork, which is reinforced with knitted structure as outerwear.

Table 1 — Thickness and weight of tested leathers

Leather	Thickness, mm	Weight, g/m^2
Cork coated nonwoven fabric	0.875	296.15
Cork coated knitted fabric	0.449	525.00
Lamb leather brown	0.894	540.38
Lamb leather white	0.640	259.62

Table 2 — Breaking and tearing strength air, permeability and water resistance values of tested samples

Leather	Breaking strength, N	Tearing strength, N	Air permeability values, L/min	AATCC Standard spray test ratings
Cork coated nonwoven fabric	245.00	16. 63	22	70 ISO 2
Cork coated knitted fabric	288.80	16.87	24	50 ISO 1
Lamb leather brown	218.65	7.95	23	80 ISO 3
Lamb leather white	167.16	12.78	24	80 ISO 3

3.3 Tearing Strength

Since different methods and resin are used in the manufacture of cork leathers, it is predicted that they would have different backings and be affected accordingly. However, repeated tests show very similar values (Table 2). The difference in the fineness of the cork leather is not reflected in the test results. There is a noteworthy result from tearing strength that the coated vegan leathers have better tearing strength, as compared to references counterparts, even though the reference leathers have a higher thickness value. As mentioned in the tensile properties, these types of mechanical properties can be arranged by choosing backing fabrics, which helps to design specific vegan leathers. It does not have limit, like raw or processed animal leathers. The cork leather with a knitted backing has good adhesion and thinner texture along with a coating on the top which gives similar values in comparison to the thicker cork leather with a non-woven surface on the backing. Although the fineness of cork coated nonwoven fabric and lamb leather brown is close, which resembles homogeneously dispersed nonwoven structures, it is believed that cork provides better results due to its chemical structure and cell structure.

3.4 Air Permeability Test

The air permeability of a fabric is affected by its fibre, yarn, and structural form. The air permeability of the fabric is also very important for moisture behavior. The different permeability properties of the textile material, such as air, water vapor and water, affect the wearing comfort. Depending on the material's using area, air permeability is an indicator of the physical interactions between the material and its environment during active usage. As mentioned in Fig. 1, due to the larger porous cell structures of knitting backing, it has better air permeability (Table 2). The cork does not block the air transfer, as the reference leather does. It is the main problem with animal leather that it causes sweat. In this case, especially considering the structure of the fabric reinforcement, higher air permeability is anticipated as compared to leather, but the cork and adhesive material directly affect the air permeability Since the primary concern here is modeling the leather, it is assumed that the frequency of adhesion of cork to the fabric is modeled according to the air permeability of the leather. The values for air permeability are very similar to those of standard leather, as it is modelled too so However, it should be noted that the air permeability values of cork leather can be increased or decreased during the manufacture of the composite/laminated structures. This is another important advantage of designing vegan leather. For instance, while a firmer structure is expected in outerwear, higher air permeability may be desired in upholstered furniture. This is where the design advantages of this type of vegan leather come into play as compared to the conventional leather. With conventional leathers, this difference can only be determined by the type of leather, production methods, and sources of supply. Aside from being environment friendly and sustainable, it makes sense to highlight the design benefits of vegan leathers.

3.5 AATCC Spray Test

Water resistance (rain test method) test according to the AATCC 35 standard, is used to simulate the water-resistance of fabrics exposed to the weather in heavy rain. It is found that the cork leather having knitted backing retains water, where it could leak out. Lamb leather, on the other hand, during the test does not allow the water to pass through; certain drops of water stuck to the protrusions on the surface and stood in the form of a pile of beads, giving us the impression of 50 ISO 1. This property is important for both sites liquid transfer from the skin (sweat) to air or wetting from outside. It is also all about to usage area, such as outdoor applications.

3.6 Contact Angle Test

The mean value of the contact angle of the cork sample is determined to be 77.22° and the mean value of the contact angle of lamb leathers is found to be 99.26° (Fig. 3). The test has been done only on the front surface of the structures. It is considered as a conventional textile structure that is used as an outwear fabric. For this reason, only the outermost part is considered for this test. The tanning process of conventional leathers directly affect the liquid absorption properties[29]. The contact angle is an

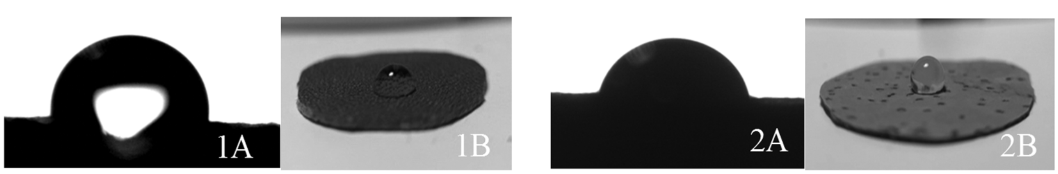


Fig. 3 — 1A/1B- lamb leather brown contact angle and 2A/2B- cork coated knitted fabric contact angle

important property to determine the hydrophobic activity of the structures. There are some studies which discuss the hydrophobic behavior of conventional leather. The main well-known problems of the conventional leathers at the wet area usage can be followed as (i) water absorption after a certain period of use, (ii) water stains, (iii) color stains and (iv) shape changes. These types of problems can be eliminated by designing cork leather with appropriate construction elements. A detailed study on the contact angle properties of cork structure is discussed. Chanut *et al.* [29] measured and modeled the contact angle properties of the cork bark and they mentioned that the cork structure has good hydrophobic behavior, which is a crucial parameter for such outdoor applications. The test method they used to measure the contact angle has a result similar to the present study.

3.7 Color Fastness Study

As can be seen in Table 3, all tested values are within the acceptable range of the standard. The color fastness grade is tested as 4-5, which is considered as a good value. In the interaction between the conventional lamb leather and the reference color fastness fabrics, the color fastness result is 2-3, as you can see with the polyester in Table 3. The lamb leathers do not pass the color fastness test against acetate and polyester.

Table 3 — Color fastness to water

Sample types	Change in color	Staining in color					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
Cork coated nonwoven fabric	4-5	5	5	5	4	4	4
Cork coated knitted fabric	4-5	5	5	5	4	4	4
Lamb leather brown	4	3	5	5	2-3	4-5	4-5

The cork leather may have various applications in textiles[30]. This test aims to investigate its interaction with backing/lining textile fabrics. It is found that the durability of the cork laminated fabrics is good even after the standard washing process. It is crucial to mention that the multiple-washing and retesting of the above-mentioned properties need to be performed in future studies. In this study, good results are obtained with the accompanying reference fabrics. As shown in Fig. 4, the textile fabrics provide good performance values after washing the fabrics used as lining at 90^{o}C [31].

3.8 Sound Absorption

Sound insulation and absorption are considered as important factors for human comfort. The preparation of environment-friendly products with good sound absorption features is an essential requirement, especially after the lockdown of the pandemic. During the pandemic, the building materials have gained great significance. The sound-proof materials are widely used in different industries, such as building, aircraft, and automobiles. The values of the sound absorption coefficient of the leather are measured in the frequency range of 80-6300 Hz using the BSWA TECH impedance tube system and method according to the ASTM 1050-98 standard. Cork mattresses, obtained by processing cork granules from cork oak wood, are used in the industry as a sound-absorbing and insulating material to provide solutions to vibration problems, such as heel noise on floors[32,33]. The test has been conducted to observe the condition of cork-leathers. The values of the sound absorption coefficient of the leathers are measured in the

Fig. 4 — Color fastness test result of knitted backed cork leather

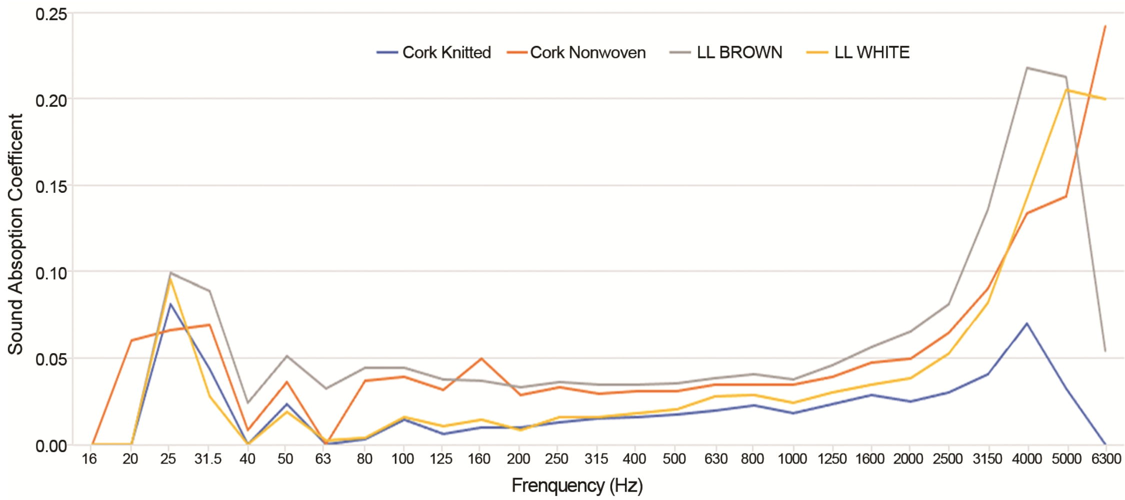


Fig. 5 — Sound absorption properties

frequency range 80-6300 Hz using the BSWA TECH impedance tube system. For the measurements in the low, medium, and high frequency range, the leathers are cut to a diameter of 100 mm and 30 mm.

The results of the sound absorption test are influenced by the fibrous structure, volumetric density, and product thickness of the samples (Fig. 5). These properties are, in order of importance, thickness, density, porous structure, coefficient of elasticity, and acoustic impedance[34].

It is assumed that the sound absorption properties of lamb leather samples would give better results due to the higher area density. When the cork samples are compared, it is found that the bulky structure of the nonwoven reinforced cork sample increases the sound absorption values as compared to the knitted structure. In the home textile market, there is a tendency towards products that emphasize eco-friendly and sustainable but also a tendency towards products with advanced and technical properties[35]. Here, it has been shown that it can be a good alternative to the already existing curtains or wallpapers made of cork leather fabric[36]. It is also found that the absorption properties after using coating materials provide similar results.

3.9 Far Infrared Radiation (FIR)

Thermal resistance and heat retention properties of the leathers are determined using an in-house method[37,38]. Five leather samples have been tested for calculating each value (Figs 6-7). The heat storage properties of the leather are measured using a thermal imaging camera (spectral range: λ = 7.5 ÷ 13 μm) Infra CAM and an IR emission lamp of 250 W, as a heat source. Before the pre-test, the IR lamp is turned on for 4 min to heat the leather. During this time, the Infra CAM is used to determine the hottest spot of the tested leather. The distance between the heat sources and the test samples is kept 25 cm. The heat source is turned off for cooling and the samples are kept again for measurement during the 4 min cooling period. The measurement continued for a total of 8 min and the images of the heat changes are taken at an interval of 15 s.

During the test, it is observed that the cork leather with knitted backing physically tends to shrink towards the fold once it is heated. Here, it is assumed that the knitted surface behind the cork leather is affected by the elastane content, resulting in a change in shape . It is observed that the cork coated knitted fabric returns to its original state when the lamp is turned off during the test and the cooling process is initiated, and no damage is seen after the test. Together with the finishes that can be applied to it, the leather can be an eco-friendly and sustainable alternative for home textiles due to its non-combustible, flame-retardant, and smoke-retardant properties[39].

The world is getting warmer day by day which emphasizes the demand for the ability of ready-made clothing and textile products to absorb heat. An example, of this, is the difference between lamb leather brown, which has the same properties as the leathers used in today's car upholstery, and cork leather, where it is observed to save similar results in terms of structural properties of cork leather with nonwoven backing. Again, the difference between LL white and cork knitted can be observed after the

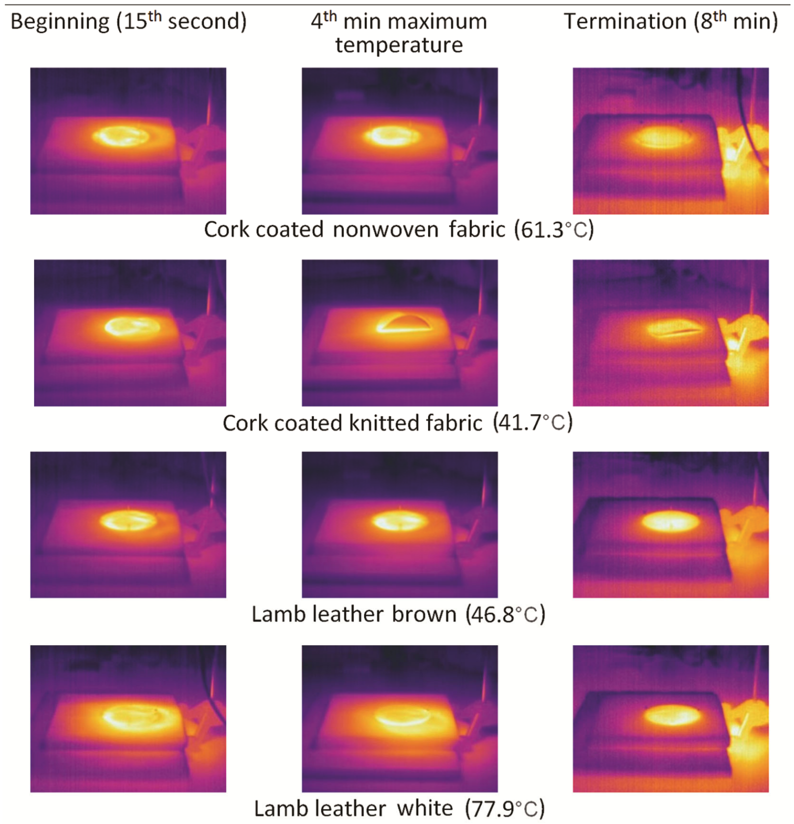
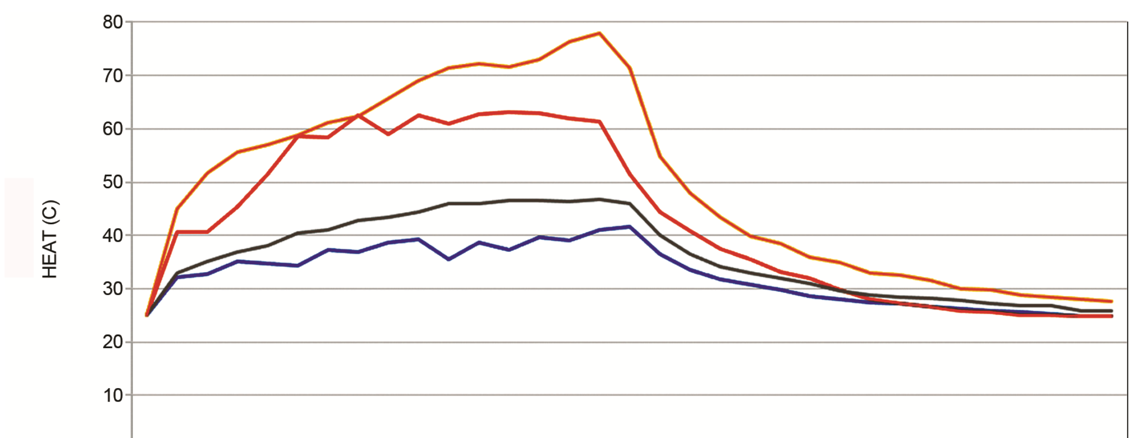


Fig. 6 — Thermograms with measured temperature of all investigated leather, recorded with thermal imaging camera



Time (s)	0	15	30	45	60	75	90	105	120	135	150	165	180	190	210
Cork Knitted	25	32.1	32.8	35.2	34.7	34.4	37.3	37	38.6	39.3	35.6	38.7	37.3	39.6	39.1
Cork Nonwoven	25	40.6	40.7	45.3	51.5	58.6	38.3	62.5	58.9	62.5	61	62.7	63.1	63	62
LL BROWN	25	32.9	35.1	36.9	38.1	40.5	41	42.9	43.4	44.3	45.9	45.9	46.5	46.6	46.4
LL WHITE	25	45	51.7	55.7	57.1	58.7	61.1	62.3	65.6	69.1	71.4	72.2	71.7	73	76.4

Time (s)	225	240	255	270	285	300	315	330	345	360	375	390	405	420	435	450	465	480
Cork Knitted	41	41.7	36.6	33.6	31.8	30.7	29.8	28.6	28	27.5	27.3	26.7	26.2	25.8	25.6	25.2	24.9	24.8
Cork Nonwoven	61.3	51.5	44.3	40.8	37.4	35.5	33.2	31.9	29.9	28.1	27.2	26.7	26.9	25.6	25.1	25.1	24.9	24.8
LL BROWN	46.8	46	40.1	36.6	34.2	33	31.9	30.9	29.7	28.9	28.4	28.2	27.9	27.2	26.9	26.8	25.8	25.8
LL WHITE	77.9	71.4	54.9	48	43.4	39.9	38.5	35.9	34.9	33	32.6	31.6	30	29.8	28.9	28.5	28.1	27.6

Fig. 7 — Dynamic thermal behavior of leathers

heating process. The cork bark has very low thermal conductivity due to its high air content and small cell size. In fungi (Fig. 1), small and closed cells prevent gas convection, and with a large number of cells, it is reduced by absorption[40]. It can be said that there are suitable properties when the breathability and heat storage capacity are expected from the cork leather.

4 Conclusion

A sustainable and eco-friendly raw material that comes from a self-renewing source, like cork, is gaining more and more value today due to the increasing demand for natural products. New techniques and methods are being researched to develop new composite and laminate structures based on cork. The unique mechanical and physical properties of cork, without compromising and deteriorating its ecological properties, are attracting much attention in the textile and non-leather sectors. The studies on the stain resistance or self-cleaning possibilities of the product will play a crucial role in its application in the near future. When the cork is harvested, the cork bark regenerates itself. Cork trees store CO_2 to regenerate, so a harvested cork tree absorbs 3-5 times more than one that is not harvested, benefiting the atmosphere. The properties of cork fabric are unique, such as warm, soft, lightweight, environment friendly, stable, stain-resistant, unique natural texture, durable like leather, versatile like conventional fabrics, and flame retardant.

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References

1 Gandia A, Brandhof J G, Appels F & Jone M P, *Trends in Biotechnology,* 39 (2021) 1321. Doi: 10 1016/j tibtech 2021 03 002.

2 Meyer M, Dietrich S, Schulz H & Mondschein A, *Coatings,* 11 (2021) 226. Doi: doi.org/10 3390/coatings11020226, 2021.

3 Pereira H V T M, Non-Wood Products – Cork Oak, *Encyclpedia of Forest Science* (Elsevier Academic Publishing), 2004, 613.

4 Alpacar K, *J Forestry Res Inst,* 20 (1973) 55.

5 Günal N, *Turkish J Geography ,* 44 (2014) 1.

6 Silva F, *Int J Environ Studies,* 63 (2006) 235. Doi:10 1080/00207230600720829.

7 Ciesla W M, *Non-Wood Forest Products from Temperate Broad-Leaved Trees* (Food and Agriculture Organization of the United Nations, Rome), 2002.

8 Costa A, Pereira H, Oliveira A, *Annals Forest Sci,* 59 (4) (2002) 429. Doi: 10 1051/forest:2002017.

9 Costa-e-Silva F, Correia A C, Pinto CA, David JS, Hernandez-Santana V & David TS, *Forest Ecology Managment,* 486 (2021). Doi: https://doi.org/10.1016/j.foreco.2021.118966.

10 Pereira H, *Cork: Biology, Production and Uses* (*Ist edn*) (Elsevier, Amsterdam), 2007 .

11 Wang Q, Lai Z, Luo C, Zhang Jing, Cao Xudong, Liu Jiao & Mu Jun, *J Hazardous Materials,* 416 (2021). Doi: https://doi.org/10.1016/j.jhazmat.2021.125896.

12 Ana Mestre J V & Vogtlander J, *J Cleaner Production,* 57 (2013) 101. Doi: https://doi.org/10.1016/j.jclepro. 2013.04.023.

13 Hızal K T, *Eurasia Term Magazine ,* 9 (2) (2021) 12. Doi: 10 31451/ejatd 911299.

14 Borges J, Oliveria M & Costa Maria A, *Forest Ecology and Managment,* 97 (3) (1997) 223. Doi: https://doi.org/10.1016/S0378-1127(97)00064-9 .

15 Bozkurt Y E, *Wood Anatomy*, İ.Ü. Faculty of Forestry Publication No. 4263/466 (2000) 269.

16 Varela M C, Cork and the Cork Oak System, *Unasylva,* 50 (1999) 42.

17 Aroso I M, Araujo A R, Pires R A & Reis R L, *ACS Sustainable Chem Eng,* 5 (12) (2017) 11130. Doi: 10 1021/acssuschemeng 7b00751.

18 Zhang X, Elsayed I, Song X, Shmulsky R & Hassan El Barbary, *Sci Total Environ,* 748 (2020) 142465. Doi: https://doi.org/10.1016/j.scitotenv.2020.142465.

19 Babayiğit I, *The Role and Importance of Cork Oak (Quercus suberL) in the Establishment of Industrial Forest Plantations* in Turkey, İzmir: İlhan Sanater LTD ŞTİ, 2004 .

20 Lagorce-Tachon A, Mairesse F, Karbowiak T, Gougeon R D, Bellat Jean-Pierre & Simon Jean-Marc, *J Chemom,* 32 (1) (2017) 2988. Doi: https://doi.org/10.1002/cem.2988.

21 Yaltırık F, *Forest Hunting,* 27(1955) 113.

22 Teixeira S, Santos JLC & Crespo JG, *Seperation Purification Technol,* 66(1) (2009) 35.

23 Nurchi V M, Alonso M C, Biesuz R & Alberti G *Arabian J Chem,* 7 (1) (2014)133. Doi: http://dx.doi.org/10.1016/j.arabjc.2013.07.006.

24 Gil L, *Sci Technol Materials,* 30 (2018) 80.

25 Crouvisier-Urion J K, Chanut J, Lagorce A, Winckler P, Wang Zi, Verboven P, Nicolai B, Lherminier J, Ferret E, Gougeon R D, Bellat J-P & Karbowiak T, Four hundred years of cork imaging: new advances in the characterization of the cork structure, *Scientific Reports,* 9, (Artcile No. 19682) (2019). Doi: https://doi.org/10.1038/s41598-019-55193-9.

26 Anjos O, Rodrigues C, Morais J & Pereira H, *Materials Design,* 53 (2014) 1089. Doi:10.1016/j.matdes.2013.07.038 .

27 Mano J F, *J Material Sci,* 37 (2002) 257.

28 Li X, Liu R, Long L, Liu B, Xu J, *Composite Structures,* 258 (2021) 113376. Doi: https://doi.org/10.1016/ j.compstruct. 2020. 113376.

29 Chanut J, Wang Y, Cin I D, Ferret E, Gougeon R D, Bellat J-P & Karbowiak T, *J Colloid Interface Sci,* 608 (2022) 416. Doi: https://doi.org/10.1016/j.jcis.2021.09.140.

30 Karbowiak T, Mansfield A K, Barrera-Garcia V D, Chassagne D, *Food Chem,* 122 (2010) 1089. Doi: 10.1016/j.foodchem.2010.03.089 .

31 Lequin S, Chassagne D, Karbowiak T, Gougeon R,Brachais L & Ballet J-P, *J Agric Food Chem,* 58 (6) (2010) 3438. Doi: https://doi.org/10.1021/jf9039364.

32 Umberto Berardi G I & Iannace G, Acoustic characterization of natural fibers for sound absorption applications, *Building and enviroment,* 94 (2015) 840. Doi: http://dx.doi.org/10.1016/j.buildenv.2015.05.029.

33 Knapic Sofia, Machado J S & Pereira H, *Construction Building Materials,* 30 (1) (2012)569. Doi: http://dx.doi.org/10.1016/j.conbuildmat.2011.11.014 .

34 Tedjditi A K, Ghomari F, Belarbi R & Cherif R, *Construction Building Materials,* 317 (8) (2022) 25905. Doi: http://dx.doi.org/10.1016/j.conbuildmat.2021.125905.

35 Abenojar J, Barbosa A Q, Ballesteros Y, del Real-Romero JC, Da Silva LSM & Martinez MA, *Wood Sci Technol,* 48(1)(2014) 207. Doi: https://dx.doi.org/10.1007/s00226-013-0599-7.
36 Novais R M, Senff L, Carvalheiras J, Lacasta AM, Cantalapiedra I R & Labrincha J A, *J Building Eng,* 42(2021) 102501. Doi: https://doi.org/10.1016/j.jobe.2021. 102501.
37 Audrone V R -G Sankauskaite, *Polymers*, 12(6) (2021) 1120. Doi: https://doi.org/10.3390/polym13071120.
38 Laimutė Stygienė S G, Varnaite-Zuravliova S, Abraitiene A, Krauledas S, Baltusnikaite-Guzaitiene J & Padleckiene I, *J Industrial Text,* 50 (5) (2019)716. Doi: https://doi.org /10.1177 /1528083719842793 .
39 Zhai W, Zhong Y & Wei X, *Ind Crops Prod,* 157 (6) (2020) 112932. Doi: http://dx.doi.org/10.1016/j.indcrop. 2020.112932.
40 Silva S P, Sabino M A, Fernandes E M, Correlo VM, Boesel LF & Reis RL, *Int Materials Rev,* 50(6) (2005) 345. Doi: https://doi.org/10.1179/174328005X41168.