Textile & Leather Review

ISSN 2623-6281 | www.tlr-journal.com | 10.31881/TLR

Hydrophobic Coating of Vegetable-Tanned Leather with Dodecylamine

Nur Mutia Rosiati, Mustafidah Udkhiyati, Fitrilia Silvianti

How to cite: Rosiati NM, Udkhiyati M, Silvianti F. Hydrophobic Coating of Vegetable-Tanned Leather with Dodecylamine. Textile & Leather Review. 2024; 7:569-581. https://doi.org/10.31881/TLR.2024.040

How to link: https://doi.org/10.31881/TLR.2024.040

Published: 11 April 2024

Hydrophobic Coating of Vegetable-Tanned Leather with Dodecylamine

Nur Mutia ROSIATI[1*], Mustafidah UDKHIYATI[1], Fitrilia SILVIANTI[2]

[1]Department of Leather Processing Technology, Politeknik ATK Yogyakarta, Sewon, Bantul 55281, Yogyakarta, Indonesia

[2]Department of Rubber and Plastic Processing Technology, Politeknik ATK Yogyakarta, Sewon, Bantul 55281, Yogyakarta, Indonesia

*mutiarosiati@atk.ac.id

Article

https://doi.org/10.31881/TLR.2024.040

Received 16 February 2024; Accepted 08 April 2024; Published 11 April 2024

ABSTRACT

Vegetable-tanned leather exhibits a hydrophilic character due to the abundance of hydroxyl groups (-OH). In this study, the surface of vegetable-tanned leather was modified to become hydrophobic. The leather was coated using dodecylamine (DDA) through the padding method in the finishing process. The concentration of DDA varied from 1%, 2%, 3%, and 4% to identify the optimum concentration. The coating process was assisted by an activator, either acid or base, to improve the adhesion of DDA to leather. Uncoated vegetable-tanned leather was used as a control. The success of coating was identified using FT-IR and SEM-EDX analysis. The hydrophobicity of leather was conducted through a water resistance test. The success of coating is shown by the increase in their weight and thickness. Absorption bands of alkyl and amino groups of DDA are observed in FT-IR spectra around 1450 cm^{-1} and 3400 cm^{-1}, respectively. SEM micrographs show that coated leathers have flatter surfaces as a consequence of DDA attachment on the leather surface. The water resistance test proves that the use of DDA can improve the leather hydrophobicity and enhance the water absorption time by up to 4 times. The optimum water absorption time is obtained when using 2% DDA.

KEYWORDS

vegetable-tanned leather, dodecylamine, hydrophobic coating, water resistance

INTRODUCTION

Currently, the leather tanning process still widely uses chrome(III) as a tanning agent. However, chrome(III) is known to be easily oxidized to chrome(VI), so its use should be minimized. One alternative tanning agent is a vegetable tanning agent. Vegetable tanning agents contain polyphenols so they have lots of hydroxyl (-OH) groups. This causes vegetable-tanned leather to have hydrophilic properties [1]. The hydrophilicity of leather increases the ability to absorb water. Dirt carried by water can stick to the surface of leather, making it easily dirty and becoming a good medium for bacterial growth. Therefore, it is necessary to alter the leather surface to become hydrophobic.

The application of leather in various goods, such as footwear and garments, requires the leather to have water-resistant properties. Water-resistant properties can be created by imitating the

superhydrophobic character of taro leaf structure [2]. Taro leaf is composed of a hierarchical structure with micropapillae formed by the self-assembly of long-chain hydrocarbon waxes that make the surface hydrophobic [3]. Several ways to improve the hydrophobicity of leather can be conducted using a water-repellent material in the retanning, fatliquoring, or finishing process. Its use in the retanning or fatliquoring process allows the material to penetrate through the cross-section and collagen fibres to be coated perfectly. Meanwhile, its use in the finishing process produces a hydrophobic layer on the leather surface [4].

Leather coating in the finishing process is considered easier and more efficient because it requires less time and supporting chemicals. Many alternative coating methods have been developed to obtain hydrophobic surfaces, including plasma polymerization [4-7] and spraying methods [8]. One finishing method that is often applied is the padding method. In this method, the chemical used can be transferred optimally onto the leather [9].

Several studies have reported surface modifications with silica and fluoro compounds, both on natural and synthetic leather [3,8,10]. However, fluorinated compounds have negative effects on the environment, including contamination, bioaccumulation, and high toxicity [11]. Organosilane has been developed to produce hydrophobic leather with a water contact angle of 135-140° [4,10,12]. Its hydrophobic character is ascribed to the long-chain hydrocarbon of organosilane. Likewise, dodecylamine (DDA) has been reported to provide hydrophobic, water-repellent, and self-cleaning characteristics [2,13,14]. DDA contains an amino group that interacts with water molecules strongly and a long-chain hydrocarbon that provides hydrophobic properties [14]. This hydrophobic character is the reason for using DDA in leather coating material in this study. Modification of vegetable-tanned leather with DDA is assisted by an activator to improve adhesion. Two types of activators, which are acid and base, are selected to investigate the most optimal for use in the leather coating process.

EXPERIMENTAL

Materials and Methods

Materials

Materials used were mimosa-tanned goat leathers (produced by Politeknik ATK Yogyakarta), isopropyl alcohol 95% (technical grade), citric acid (PT Golden Sinar Sakti), ammonia (technical grade), and dodecylamine (DDA, Merck).

Methods

The coating process was done for leather finishing by padding method. Tanned leathers were cut into pieces of 15 x 15 cm and then wiped with 5 mL of isopropyl alcohol for clarity. After drying at room

temperature, every piece of leather was wiped using 5 mL of an activator (acid/base) and then dried at room temperature. About 5 mL of DDA solution in various concentrations was wiped onto it and then dried (Table 1). The coated leathers were characterized using FT-IR analysis (Perkin Elmer 96681) [15-18], SEM-EDX analysis (JEOL JSM-6510LA) [1,19,20], and water resistance test.

To identify the functional groups of leather, the sample was cut to 0.5 x 0.5 cm. This piece was put in the sample holder of an FT-IR spectrophotometer and the absorbance was measured at a wave number range of 400-4000 cm^{-1}. The morphology and elemental content of leather were determined using SEM-EDX with 20 kV power and 100 μm magnification. A drop test method was carried out to identify the water resistance of leather. A 5 μL of water droplet was dripped on the surface of the leather at a distance of 3 cm. The water absorption time was determined.

Table 1. Variations in the use of chemicals for coating process

Sample	Activator	Concentration of DDA (%wt)
Control	-	-
A1	Acid (Citric acid 2.5%)	1
A2	Acid (Citric acid 2.5%)	2
A3	Acid (Citric acid 2.5%)	3
A4	Acid (Citric acid 2.5%)	4
B1	Base (Ammonia 2.5%)	1
B2	Base (Ammonia 2.5%)	2
B3	Base (Ammonia 2.5%)	3
B4	Base (Ammonia 2.5%)	4

RESULTS AND DISCUSSION

Coating Process

Adhesion plays an important role in the finishing process attributing to the interaction of leather surface and finishing chemical. Generally, adhesion in the finishing process occurs with a combination of mechanisms. Adhesion mechanisms that may be found are mechanical adhesion, chemical bonding, and diffusion adhesion [21].

Hydrogen ions (H^+) from acid activator make the surface of leather positively charged. Likewise, DDA has a positive charge attributed to an amino group [22]. This similarity charge causes good penetration and leads to slow adhesion on the leather surface [23-25]. After contacting and penetrating the leather, DDA binds to the leather through hydrogen bonding. In this case, the possible adhesion mechanisms are mechanical adhesion and chemical bonding. The hypothetical hydrogen bonding that forms is presented in Figure 1. Hydrogen bonding is included in chemical bonding even though it is

considered a weak interaction. The large number of these bondings on the leather surface still has a significant effect [21].

Ammonia as a base activator produces hydroxide ions (OH^-) and provides a negative charge to leather. Consequently, the leather charge which was initially positive resulting from its pH being below the isoelectric point (IEP), changes to become negative. The opposite charges between the leather and DDA prevent DDA from penetrating the leather, resulting in the formation of hydrogen bonding on the leather surface directly [23]. Thus, the adhesion mechanism when using a base as an activator is chemical bonding. Therefore, it is concluded that acid and base can be used as activators in the leather coating process with DDA despite different levels of penetration depth.

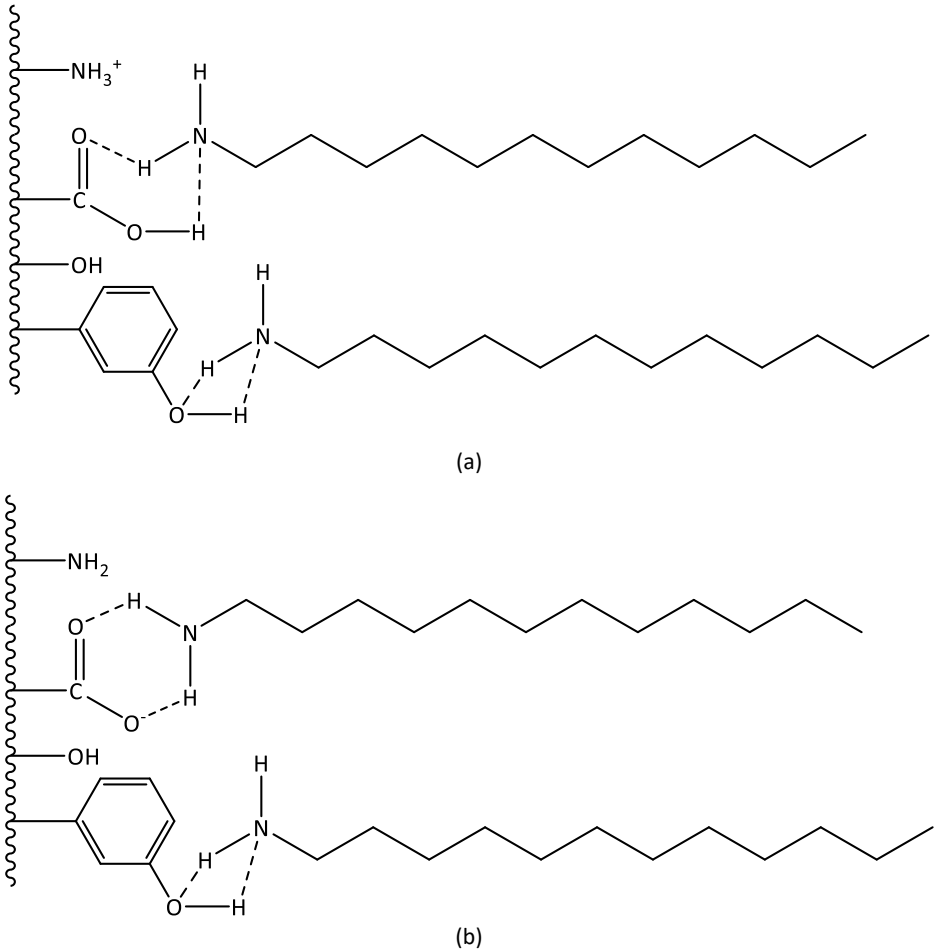


Figure 1. Hypothetical structure of coated vegetable-tanned leather: (a) using an acid activator and (b) using a base activator

Physical Properties

Modification of leather using DDA results in an increase in its weight and thickness. Table 2 shows that the weight of every treatment has increased but not significantly. Likewise, there is an increase in its

thickness but it is not significant. This phenomenon occurs because of the small amount of DDA used. However, this implies the success of leather coating.

Table 2. Weight and thickness of leathers modified with DDA

Sample	Weight (g)			Thickness (μm)		
	Before	After	Difference	Before	After	Difference
A1	13.81	13.84	0.02	720.2 ± 58.7	728.2 ± 54.8	8.0
A2	15.19	15.21	0.02	789.2 ± 74.8	796.2 ± 77.3	7.0
A3	16.42	16.56	0.14	946.4 ± 74.9	955.8 ± 65.9	9.4
A4	14.72	14.78	0.06	840.3 ± 110.6	852.7 ± 66.6	12.3
B1	13.23	13.24	0.01	720.0 ± 27.2	721.7 ± 29.3	1.7
B2	17.20	17.37	0.18	1029.8 ± 82.1	1037.6 ± 81.3	7.8
B3	15.68	15.73	0.05	917.0 ± 43.9	928.6 ± 47.7	11.6
B4	14.46	14.57	0.10	807.6 ± 64.8	822.6 ± 44.1	15.0^{s}

Note: s: there is a significant difference between the two groups ($P < 0.05$)

Functional Groups Identification

Infrared spectra of control and leather modified with DDA can be seen in Figure 2. Characteristic absorptions of vegetable-tanned leather are observed from the presence of amide, methylene, and hydroxyl groups. Amide I appears at a wavenumber range of 1642-1651 cm^{-1} as a carbonyl group (C=O) stretching vibration [1,17,26]. The vibration band at 1539-1558 cm^{-1} is a result of overlapping between C-N of amide II stretching and N-H bending [1,27,28]. Amide III is shown at a range of 1234-1236 cm^{-1} from carboxylate group stretching [17,28,29]. The methylene group is detected at 1455-1458 cm^{-1} from its bending vibration [18]. Furthermore, absorption of C-H asymmetric stretching vibration appears at 2926-2927 cm^{-1} [30]. Vibration broadband at 3339-3406 cm^{-1} is identified as O-H stretching [31]. Stretching of C-O-C from vegetable tannin results in a band at 1033-1090 cm^{-1} [17,32].

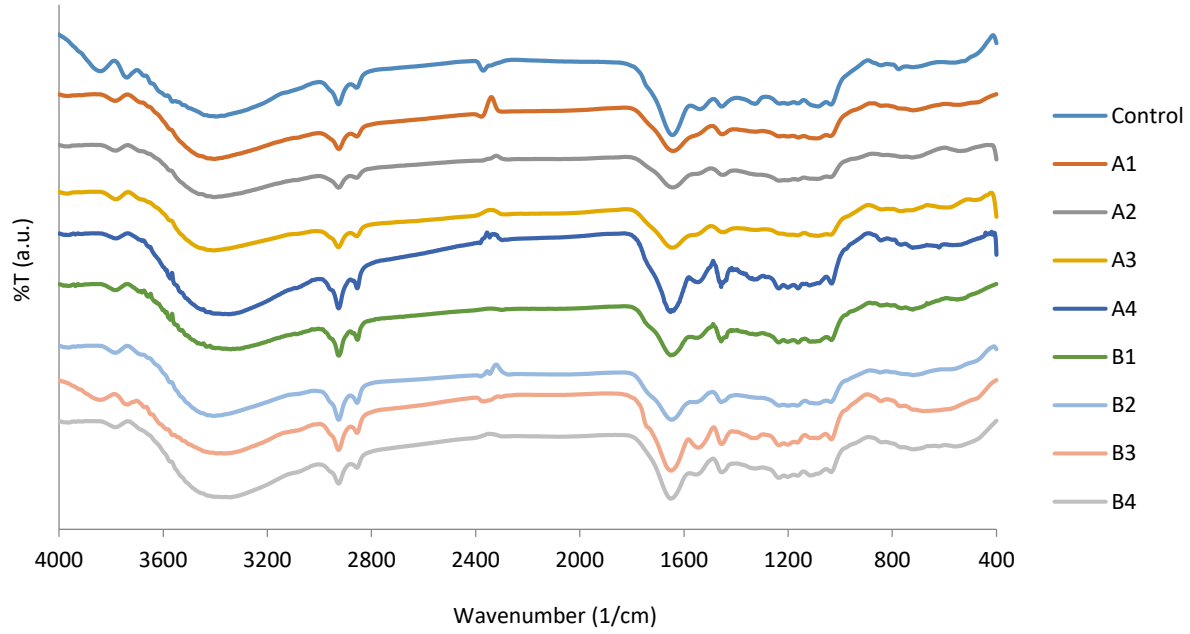
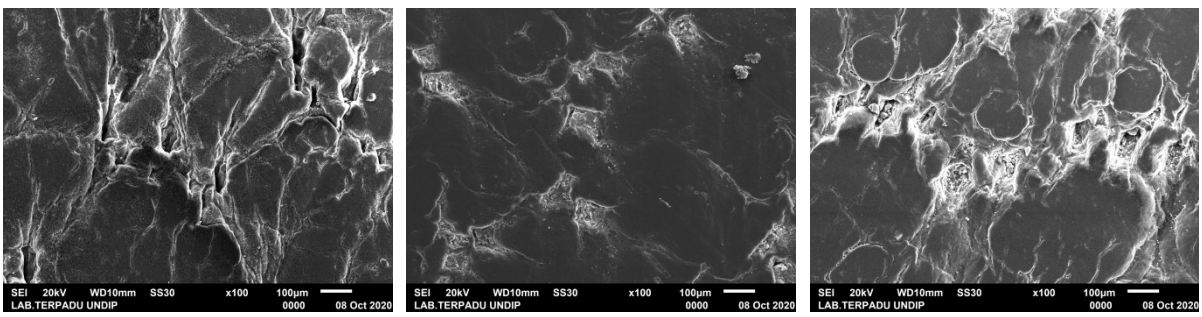


Figure 2. FT-IR spectra of leathers: control, A1, A2, A3, A4, B1, B2, B3, and B4

The presence of DDA on the leather results in slightly different intensities of the absorption band. This is due to the same functional group content of DDA as the leather which exhibits methyl, methylene, and amino groups. When compared with the control absorption band, the alkyl groups of DDA give a higher intensity of absorption band at 1455-1458 cm^{-1}. This proves the success of DDA attachment to the leather. Characteristic absorption of the amino group is commonly observed at 1628 cm^{-1} and 3426 cm^{-1} as bending and stretching of -NH bond, respectively [33]. In this research, that absorption band overlaps with -OH of leather vibration. However, the absorption bands around 3400 cm^{-1} are observed to become wider as the amount of DDA used increases. Moreover, Figure 2 shows that there is no difference in the absorption band for the use of acid or base in the modification process. This indicates that both can be used for the leather modification process with DDA.

Morphology and Elemental Analysis



Control A1 A2

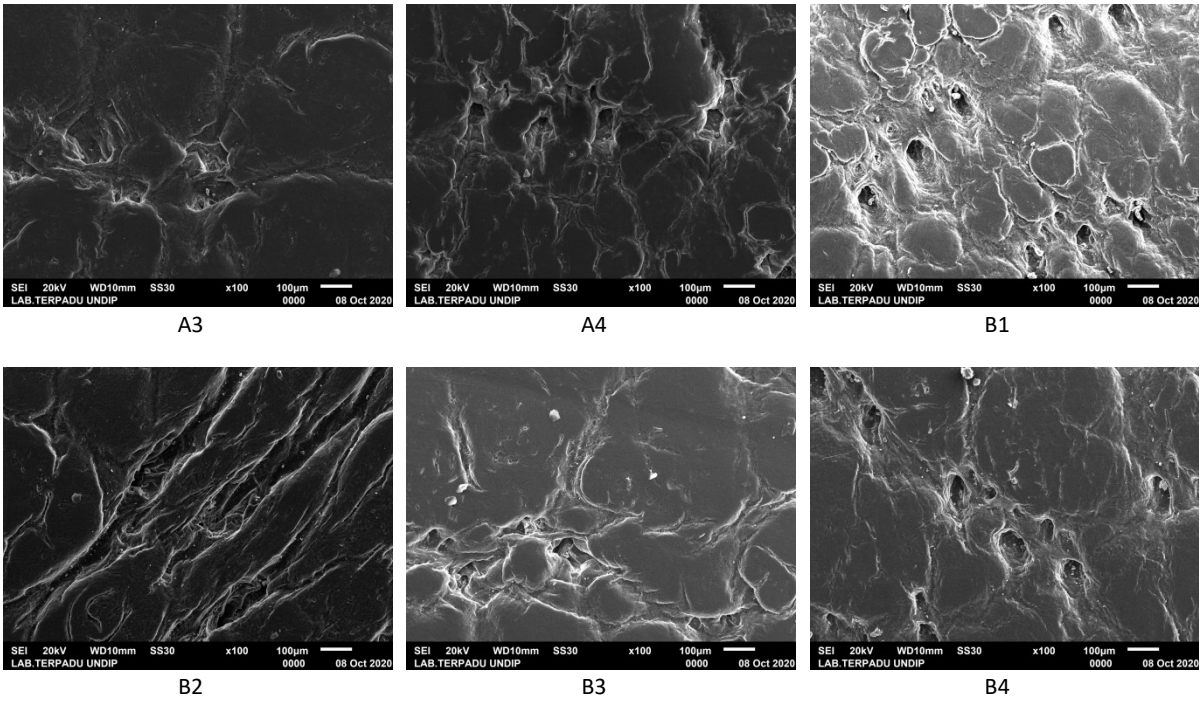


Figure 3. SEM images of leathers: control, A1, A2, A3, A4, B1, B2, B3, and B4

SEM micrographs indicate that the control has more cavities than modified leathers (Figure 3). Meanwhile, the modified leather exhibits a flatter surface due to the cavity closure by DDA. The micrographs show that base-activated leathers have more porous surfaces than acid-activated leathers. This is caused by the alkali swelling that opens up the fibres' structure as a consequence of the opposite charges between the leather and DDA when using a base activator [21].

The elemental content of leather is written in Table 3. It is known that the highest content of leather, both control and modified leather, is carbon (C). The presence of DDA hydrocarbon groups generally causes an increase in the percentage of C in modified leather compared to the control. However, it is seen that there is a decrease in C content for A1 and A2, which is aligned with the increase of O and Si content. This phenomenon allegedly occurs due to the presence of impurities during the process.

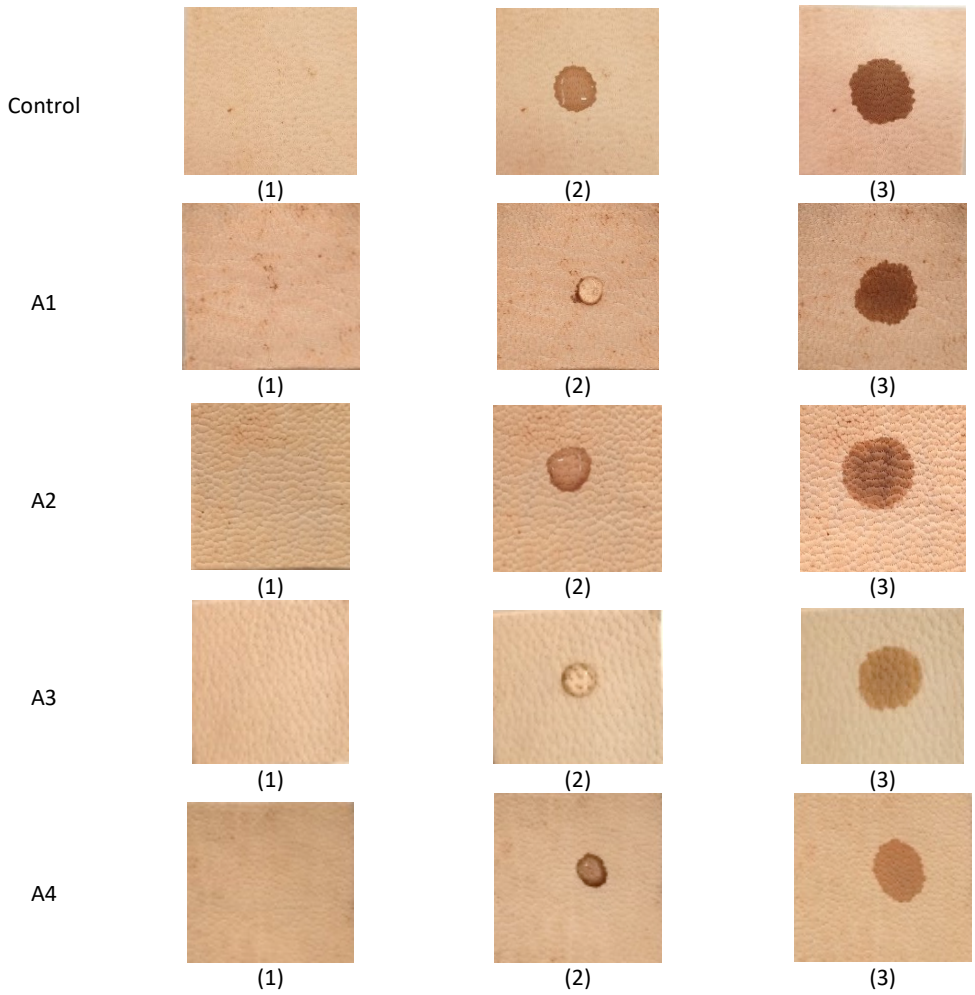
Table 3. Elemental content of leather

Sample	Chemical composition (%wt)					
	C	O	Na	Si	S	Ca
Control	63.23	33.23	2.16	0.08	1.00	0.15
A1	61.29	34.42	2.21	0.75	1.02	0.15
A2	62.10	33.78	1.55	1.16	0.99	0.32
A3	67.92	29.82	0.65	0.34	0.84	0.36
A4	65.56	32.49	0.98	-	0.89	0.08
B1	64.69	32.40	1.01	0.29	0.99	0.19
B2	70.01	26.91	-	0.15	1.05	0.84

Sample	Chemical composition (%wt)					
	C	O	Na	Si	S	Ca
B3	68.55	29.47	0.77	0.10	0.95	0.16
B4	64.52	32.38	0.89	0.12	0.97	0.27

Water Resistance Properties

A drop test was carried out to determine the effect of DDA on the water resistance of leather. This method is considered easier and faster than the contact angle measurement method [34]. The appearance of leather can be seen in Figure 4. The use of vegetable tanning agents leads to the hydrophilicity of leather so that the contact angle between the water droplet and the leather surface is less than 90°. The hydrophilicity of leather remains visible with perfect water absorption into the leather (Figure 4). However, the results of water absorption time show that the use of DDA can increase the water absorption time up to 4 times (Table 4). This is under the hypothesis that the presence of a hydrocarbon chain in DDA can increase the hydrophobicity of leather. This causes water to be retained on the surface of the leather. Therefore, it is concluded that DDA is effective as a water-repellent agent for leather.



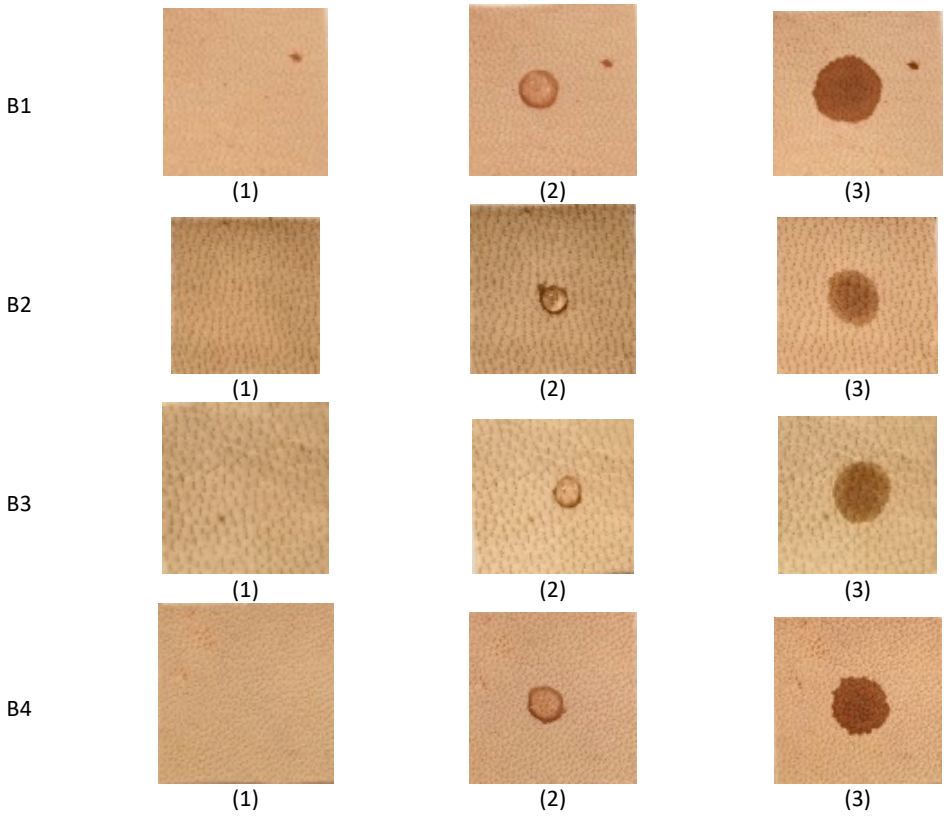


Figure 4. Visual of leathers: control, A1, A2, A3, A4, B1, B2, B3, and B4; (1) before dripping water, (2) after dripping water, and (3) after absorbing water

Table 4. Time for water absorption

Sample	Absorption time (s)
Control	23.98 ± 1.82[a]
A1	75.77 ± 14.21[c]
A2	106.24 ± 10.81[d]
A3	70.04 ± 7.46[b,c]
A4	51.31 ± 6.93[b]
B1	70.40 ± 7.28 [b,c]
B2	110.86 ± 17.99[d]
B3	110.59 ± 22.09 [d]
B4	99.86 ± 18.42[d]

Note: a, b, c, and d show real differences ($P < 0.05$)

Table 4. informs that the time for water absorption of leather increases with the use of DDA. This proves that the hydrocarbon chain of DDA is successfully attached to the leather and improves its hydrophobicity [35]. However, absorption time decreases after using 2% DDA for both acid or base activators. Excess amount of DDA over the number of active groups on leather leads to the inability of DDA to reattach to the leather [23].

CONCLUSION

Coating of leather using DDA succeeded in increasing leather hydrophobicity which is proven by an increase in the absorption time of water on leather surface. The success of coating is shown by the increase in their weight and thickness. FT-IR and SEM-EDX analysis results also confirm that DDA was successfully attached to vegetable-tanned leather. A water resistance test proves that the use of DDA can improve the leather hydrophobicity and enhance the water absorption time by up to 4 times. The optimum water absorption time is obtained when using 2% DDA. However, it is still necessary to study the release ability of DDA from leather.

Author Contributions

Conceptualization – Rosiati NM; methodology – Rosiati NM; formal analysis – Udkhiyati M and Silvianti F; investigation – Rosiati NM and Udkhiyati M; resources – Rosiati NM and Silvianti F; writing-original draft preparation – Rosiati NM and Udkhiyati M; writing-review and editing – Rosiati NM, Udkhiyati M and Silvianti F; visualization – Rosiati NM and Udkhiyati M; supervision – Rosiati NM. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This research was funded by Politeknik ATK Yogyakarta, Research Grant of Riset Pembinaan 220/2020.

REFERENCES

[1] Rosiati NM, Udkhiyati M. Citric Acid as an Effective and Safe Fixing Agent in Vegetable Tanning Process of Goatskin. Leather and Footwear Journal. 2022; 22(4):267-274. https://doi.org/10.24264/lfj.22.4.3

[2] Kartini I, Santosa SJ, Febriyanti E, Nugroho OR, Yu H, Wang L. Hybrid Assembly of Nanosol Titania and Dodecylamine for Superhydrophobic Self-Cleaning Glass. Journal of Nanoparticle Research. 2014; 16:2514. https://doi.org/10.1007/s11051-014-2514-z

[3] Gurera D, Bhushan B. Fabrication of Bioinspired Superliquiphobic Synthetic Leather with Self-Cleaning and Low-Adhesion. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 2018; 545:130-137. https://doi.org/10.1016/j.colsurfa.2018.02.052

[4] Feng Y, Liao X, Wang Y, Shi B. Improvement in Leather Surface Hydrophobicity through Low-Pressure Cold Plasma Polymerization. Journal American Leather Chemists Association. 2014; 109(03):89-95.

[5] Kayaoğlu BK, Öztürk E. Imparting Hydrophobicity to Natural Leather through Plasma Polymerization for Easy Care Effect. Fibers and Polymers. 2013; 14:1706-1713. https://doi.org/10.1007/s12221-013-1706-y

[6] Kayaoğlu BK, Öztürk E, Guner FS, Uyar T. Improving Hydrophobicity on Polyurethane-Based Synthetic Leather through Plasma Polymerization for Easy Care Effect. Journal of Coating Technology and Research. 2013; 10:549-558. https://doi.org/10.1007/s11998-013-9470-x

[7] Silvestre CR, Blasco MPC, López SR, Aguilar HP, Limiñana MÁP, Gil EB, Calpena EO, Ais FA. Hydrophobic Lether Coating for Footwear Applications by a Low-Pressure Plasma Polymerisation Process. Polymers. 2021; 13(20):3549. https://doi.org/10.3390/polym13203549

[8] Ferrero F, Periolatto M, Gozzelino G. Sol-gel process for surface modification of leather. In: Chandra U, editor. Recent Applications in Sol-Gel Synthesis. London, UK: IntechOpen; 2017. p. 283-299. http://dx.doi.org/10.5772/67837

[9] Acikel SM. Development of Commercial Flame Retardant in Upholstery Leathers by Boron Derivatives. Tekstil ve Konfeksiyon. 2018; 28(4):319-323.

[10] Fan Q, Ma J, Xu Q. Insights into Functional Polymer-Based Organic-Inorganic Nanocomposites as Leather Finishes. Journal of Leather Science and Engineering. 2019; 1:3. https://doi.org/10.1186/s42825-019-0005-9

[11] Prusty A, Gogoi N, Jassala M, Agrawala AK. Synthesis and Characterization of Non-Fluorinated Copolymer Emulsions for Hydrophobic Finishing of Cotton Textiles. Indian Journal of Fibre and Textile Research. 2009; 35(3):264–271.

[12] Kan CW, Kwong CH, Ng SP. Atmospheric Pressure Plasma Surface Treatment of Rayon Flock Synthetic Leather with Tetramethylsilane. Applied Science. 2016; 6(2):59. https://doi.org/10.3390/app6020059

[13] Liu L, Min F, Chen J, Lu F, Shen L. The Adsorption of Dodecylamine and Oleic Acid on Kaolinite Surfaces: Insights from DFT Calculation and Experimental Investigation. Applied Surface Science. 2019; 470:27-35. https://doi.org/10.1016/j.apsusc.2018.11.104

[14] Wang L, Sun N, Wang Z, Han H, Yang Y, Liu R, Hu Y, Tang H, Sun W. Self-Assembly of Mixed Dodecylamine-Dodecanol Molecules at the Air/Water Interface Based on Large-Scale Molecular Dynamics. Journal of Molecular Liquids. 2019; 276:867-874. https://doi.org/10.1016/j.molliq.2018.12.076

[15] Puică NM, Pui A, Florescu MS. FTIR Spectroscopy for the Analysis of Vegetable Tanned Ancient Leather. European Journal of Science and Theology. 2006; 2(4):49-53.

[16] Zhang Y, Chen Z, Wang C, Tian Y, Gong D. Studies of Structure Changes of Archeological Leather by FTIR Spectroscopy. Journal-Society of Leather Technologists and Chemists. 2018; 102(5):262-267.

[17] Rosiati NM, Silvianti F, Udkhiyati M. Characterization of Silica/Silver-based Antibacterial Leather. Leather and Footwear Journal. 2020; 20(2):109-118. https://doi.org/10.24264/lfj.20.2.2

[18] Rachmawati L, Anggriyani E, Rosiati NM. Technology of Free Chrome Tanning Process: Optimal Level of Formaldehyde as Tanning Agent for Mondol Stingray (*Himantura gerrardi)*. Leather and Footwear Journal. 2020; 20(3):277-286. http://dx.doi.org/10.24264/lfj.20.3.6

[19] Jawahar M, Vani K, Babu NKC. Leather Species Identification Based on Surface Morphological Characteristics using Image Analysis Technique. Journal American Leather Chemists Association. 2016; 111:308-314.

[20] Stanca M, Gaidau C, Alexe CA, Stanculescu I, Vasilca S, Matei A, Simion D, Constantinescu RR. Multifunctional Leather Surface Design by Using Carbon Nanotube-Based Composites. Materials. 2021; 14(11):3003. https://doi.org/10.3390/ma14113003

[21] Covington AD, Wise WR. Tanning Chemistry The Science of Leather. Northampton, UK; Royal Society of Chemistry; 2020. p. 568-570.

[22] Ripmeester M, Duford DA, Yuan S. Understanding the Behaviour of Dodecylamine as a Model Cationic Collector in Oil Sands Tailings Dewatering Applications Using a Novel FTIR Based Method. The Canadian Journal of Chemical Engineering. 2020; 98(7):1471-1482. https://doi.org/10.1002/cjce.23707

[23] Guthrie-Strachan J, Flowers K. Protein and Leather Charge. World Leather. 2005; 18, 19-23.

[24] Kanth S, Ipe A, Madhan B, Venba R, Dhathathreyan A. Effect of Different Retanning Systems on Surface Properties of Leather. Journal American Leather Chemists Association. 2007; 102(4):135-142.

[25] Wang Y, Huang W, Zhang H, Tian L, Zhou J, Shi B. Surface Charge and Isoelectric Point of Leather: A Novel Determination Method and its Application in Leather Making. Journal American Leather Chemists Association. 2017; 112(7):224-231.

[26] Ramalingam S, Sreeram KJ, Rao KJ, Nair BU. Organic nano-colourants: A-self Fixed, Optothermal Resistive Silica Supported Dyes for Sustainable Dyeing of Leather. ACS Sustainable Chemistry & Engineering. 2016; 4(5):2706-2714. https://doi.org/10.1021/acssuschemeng.6b00218

[27] Bekale L, Agudelo D, Tajmir-Riahi HA. Effect of Polymer Molecular Weight on Chitosan-Protein Interaction. Colloids and Surfaces B: Biointerfaces. 2014; 125:309-317. http://dx.doi.org/10.1016/j.colsurfb.2014.11.037

[28] Lu Z, Xiao J, Wang Y, Meng M. *In Situ* Synthesis of Silver Nanoparticles Uniformly Distributed on Polydopamine-Coated Silk Fibers for Antibacterial Application. Journal of Colloid and Interface Science. 2015; 452:8-14. http://dx.doi.org/10.1016/j.jcis.2015.04.015

[29] Velmurugan P, Cho M, Lee SM, Park JH, Bae S, Oh BT. Antimicrobial Fabrication of Cotton Fabric and Leather Using Green-Synthesized Nanosilver. Carbohydrate Polymers. 2014; 106:319-325. https://doi.org/10.1016/j.carbpol.2014.02.021

[30] Anggriyani E, Nugroho AR, Rosiati NM. Technology of Reducing Cr(VI) on Leather Processing using Mimosa as Retanning Agent. Leather and Footwear Journal. 2019; 19(1):67-72. https://doi.org/10.24264/lfj.19.1.8

[31] Djobo YJN, Elimbi A, Dika Manga J, Djon Li Ndjock IB. Partial Replacement of Volcanic Ash by Bauxite and Calcined Oyster Shell in the Synthesis of Volcanic Ash-Based Geopolymers. Construction and Building Materials. 2016; 113:673-681. https://doi.org/10.1016/j.conbuildmat.2016.03.104

[32] Corazzari I, Nistico R, Turci F, Faga MG, Franzoso F, Tabasso S, Magnacca G. Advanced Physico-Chemical Characterization of Chitosan by Means of TGA Coupled On-Line with FTIR and GCMS: Thermal Degradation and Water Adsorption Capacity. Polymer Degradation and Stability. 2015; 112:1-9. http://dx.doi.org/10.1016/j.polymdegradstab.2014.12.006

[33] Nuryono, Rosiati NM, Rettob AL, Suyanta, Arryanto Y. Coating of 2-Aminobenzimidazole and 1-(o-Tolyl)biguanide Functionalized Silicas on Iron Sand Magnetic Material for Sorption of $[AuCl_4]$. Indonesian Journal of Chemistry. 2019; 19(2):395-404. https://doi.org/10.22146/ijc.34653

[34] Mahltig B. Smart Hydrophobic and Soil-Repellent Protective Composite Coatings for Textiles and Leather. In: Montemor MF, editor. Smart Composite Coatings and Membranes. Elsevier; 2016. p. 261-292. https://doi.org/10.1016/B978-1-78242-283-9.00010-5

[35] Abdulla-Al-Mamun M, Sarker B, Islam D, Rahman A. Novel Vegetable Tanning Techniques by *Notholithocarpus densiflorus* Extract and Fatliquoring with Indigenous Bovine Fat. Textile & Leather Review. 2023; 6:78-97. https://doi.org/10.31881/TLR.2023.006