

Innovative Application and Mechanism Analysis of Biomass Materials Derived From Coffee Grounds in Waterborne Synthetic Leather

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Received: 25 September 2025; **Accepted:** 21 October 2025; **Published:** 12 November 2025

Abstract:

With the increase of environmental protection demand, it is very important to explore the green improvement way of water-borne synthetic leather. This article focuses on the application of biomass materials derived from coffee grounds in water-borne synthetic leather. By analyzing the characteristics of this material, its function in water-borne synthetic leather is studied by mixing, coating and preparing composite fibers. Biomass materials derived from coffee grounds can effectively improve the mechanical properties, surface properties and functional characteristics of waterborne synthetic leather. For example, proper addition can enhance the tensile strength and elongation at break, surface coating can give antibacterial function, and composite fiber can enhance the toughness and wear resistance. In this article, the mechanism of action is revealed from the chemical and physical aspects, including the formation of cross-linked network by the reaction of active groups, the enhancement of physical action by porous structure and the realization of stress dispersion by uniform dispersion. Biomass materials derived from coffee grounds provides an innovative and effective direction for the sustainable development of water-based synthetic leather.

Keywords:

Coffee Grounds Biomass, Waterborne Synthetic Leather, Mechanical Properties, Functional Application, Mechanism Analysis

1. Introduction

As an important material, waterborne synthetic leather is widely used in many fields. With the enhancement of environmental awareness and the idea of sustainable development, finding green and sustainable raw materials to improve the properties of waterborne synthetic leather has become a research hotspot in the field of materials science [1]. As the main waste of coffee industry, coffee grounds have a huge output

every year. If they are not used effectively, it will not only waste resources, but also cause environmental problems [2]. Converting coffee grounds into derivative biomass materials with specific properties and applying it to water-based synthetic leather provides a new idea to solve the above problems.

At present, some raw materials and processes used in the traditional synthetic leather production process are potentially harmful to the environment and human health [3]. Although water-based synthetic leather has made progress in environmental protection, it still faces challenges such as performance improvement [4]. Biomass materials derived from coffee grounds has unique chemical composition and structure, which is expected to give innovative properties to water-based synthesis, such as enhancing mechanical properties and improving air permeability [5]. This innovative application also meets the development requirements of circular economy and can realize the resource utilization of waste.

Many scholars have done some research on the comprehensive utilization of coffee grounds, some of which involve the application of coffee grounds in adsorption materials, energy materials and other fields, but the application of biomass materials derived from coffee grounds in water-based synthetic leather is still insufficient [6]. Especially in the aspect of mechanism, there is a lack of systematic and in-depth analysis. The purpose of this study is to explore the innovative application of biomass materials derived from coffee grounds in waterborne synthetic leather, deeply analyze its mechanism, and provide theoretical support and technical reference for the sustainable development of waterborne synthetic leather industry. Through this study, it is expected to promote new breakthroughs in the performance and environmental protection of waterborne synthetic leather, expand the ways of comprehensive utilization of coffee grounds, and make contributions to the efficient utilization of resources and the green transformation of the industry.

2. Analysis on the Characteristics of Biomass Materials Derived from Coffee Grounds

To prepare biomass materials derived from coffee grounds, coffee grounds should be pretreated first. Generally, surface impurities are removed by water washing first, and then dried to reduce its water content, which is convenient for subsequent processing [7]. Common preparation methods include pyrolysis, chemical modification and so on. Pyrolysis is to heat coffee grounds in an oxygen-free or anoxic environment to decompose them into materials such as biomass charcoal with a specific structure [8]. Chemical modification is to use chemical reagents to react with the components in coffee grounds to change their chemical properties.

From the physical characteristics, biomass materials derived from coffee grounds usually has a porous structure, which gives it a large specific surface area. The larger specific surface area makes it possible to increase the contact area between water-based synthetic leather and water-based synthetic leather, which is beneficial to enhance the bonding force [9]. The material has certain flexibility, which can improve the brittleness of water-based synthetic leather to a certain extent and improve its processability. The characteristics and performance of coffee grounds derived biomass materials are summarized in Table 1:

Table 1. *Summary of Characteristics and Performance of Coffee Grounds-Derived Biomass Materials.*

Characteristic Category	Specific Characteristics	Characteristic Performance
Physical Characteristics	Porous structure, large specific surface area	Increases the contact area with water-based synthetic leather, enhancing bonding strength
Physical Characteristics	Flexibility	Improves the brittleness of water-based synthetic leather and enhances processing performance
Chemical Characteristics	Contains various organic functional groups with strong reactivity	Reacts with polymer molecules to form chemical bonds, increasing the degree of cross-linking and enhancing mechanical properties
Chemical Characteristics	Good chemical stability	Less prone to chemical changes during processing and use, ensuring stable performance
Biological Characteristics	Biocompatibility	When combined with water-based synthetic leather for products in contact with the human body, it is less likely to cause allergies, broadening the application scope

In terms of chemical characteristics, biomass materials derived from coffee grounds contains many organic functional groups, such as hydroxyl and carboxyl. These functional groups have strong reactivity and can react with polymer molecules in waterborne synthetic leather to form chemical bonds, thus improving the crosslinking degree of waterborne synthetic leather and enhancing its mechanical properties [10]. Its chemical stability is good, and it is not easy to change chemically during the processing and use of water-based synthetic leather, which ensures the stability of material properties. Figure 1 shows the microstructure of water-borne synthetic leather materials.

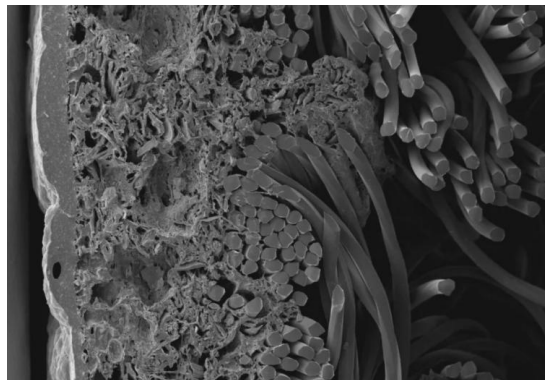


Figure 1. *Microstructure of Waterborne Synthetic Leather Materials.*

3. Innovative Application of Biomass Materials Derived from Coffee Grounds in Waterborne Synthetic Leather

Biomass materials derived from coffee grounds provides an innovative way to improve the performance and expand the function of water-based synthetic leather, which can be endowed with unique advantages through different applications [11]. As an additive, direct mixing is a common application method. In the preparation process of water-based synthetic leather, the pretreated coffee grounds-derived biomass materials was evenly mixed into the polymer system according to a certain proportion. In this process, the amount of materials added has a significant influence on the properties of waterborne synthetic leather. The research shows (as shown in Table 2) that when the dosage is 2%, the tensile strength of waterborne synthetic leather is

increased from 10MPa to 12MPa, and the elongation at break is also increased from 150% to 160%. With the increasing of the dosage to 6%, the tensile strength further increased to 15MPa, but when the dosage exceeded 6%, the tensile strength began to decline, and the elongation at break decreased to 140% when the dosage was 8%. It can be seen that the mechanical properties of water-borne synthetic leather can be effectively enhanced by adding biomass materials derived from coffee grounds.

Table 2. *Impact of Different Addition Amounts of Coffee Grounds-Derived Biomass Materials on the Mechanical Properties of Water-Based Synthetic Leather.*

Addition Amount of Coffee Grounds-Derived Biomass Materials	Tensile Strength (MPa)	Elongation at Break (%)
0% (Control group)	10	150
2%	12	160
4%	13	155
6%	15	150
8%	14	140

Surface coating is also an innovative application. Biomass materials derived from coffee grounds was made into a specific coating solution, which was coated on the surface of water-based synthetic leather by spraying and dipping. In this way, a film with special functions can be formed on the surface of waterborne synthetic leather. On the one hand, the biomass materials in the coating can fill the tiny pores on the surface of synthetic leather, improve its surface smoothness, and thus enhance the gloss and feel. On the other hand, the coating can give water-borne synthetic leather additional functions, such as antibacterial performance. Some components in biomass materials derived from coffee grounds have inhibitory effects on common bacteria. After coating, the antibacterial rates of water-based synthetic leather on *Escherichia coli* and *Staphylococcus aureus* reached 80% and 75% respectively. This effectively broadens the application of water-based synthetic leather in areas with high hygiene requirements, such as medical supplies and food packaging materials. In addition, biomass materials derived from coffee grounds can be used to prepare composite fibers, and then the composite fibers can be combined with water-based synthetic leather. This way of composite fiber reinforcement can significantly improve the toughness and wear resistance of water-based synthetic leather. In practical application, composite fibers can be embedded in the structure of water-based synthetic leather in the way of interweaving warp and weft, just like reinforcing skeleton, so that water-based synthetic leather can better disperse stress and reduce the risk of fracture and wear when bearing external force. Through this innovative application, after repeated rubbing for 5000 times, the surface wear degree of water-based synthetic leather is obviously less than that of the sample without composite fiber, which greatly prolongs the service life of water-based synthetic leather products.

4. The Mechanism of Biomass Materials Derived from Coffee Grounds in Waterborne Synthetic Leather

The function of biomass materials derived from coffee grounds in water-borne synthetic leather depends on a series of complex and interrelated physical and chemical mechanisms. From the chemical point of view, the active functional groups in biomass materials derived from coffee grounds react with water-based synthetic leather polymers, forming a stable chemical bond. Take polyurethane water-based synthetic leather as an example, its molecular chain contains a lot of isocyanate groups (-NCO), while biomass materials derived from coffee grounds is rich in

hydroxyl groups (-OH) and carboxyl groups (-COOH). Under certain conditions in the preparation of synthetic leather, isocyanate groups react with hydroxyl groups to form carbamate bonds, and the formation of this chemical bond enhances the bonding force between materials. The influence of the reaction degree of biomass materials functional groups derived from coffee grounds on the tensile strength of waterborne synthetic leather is shown in Table 3 below. With the increase of the reaction ratio of hydroxyl group and isocyanate group, the tensile strength of waterborne synthetic leather gradually increased. When the reaction ratio reaches 60%, the tensile strength is increased by 50% compared with that without reaction, which fully shows the key role of chemical crosslinking reaction in enhancing the mechanical properties of waterborne synthetic leather.

Table 3. Relationship between Chemical Reactions and Hardness.

Degree of Chemical Reaction of Coffee Grounds-Derived Biomass Materials	Hardness of Water-Based Synthetic Leather (Shore A)	Wear Resistance (Number of Times)	Tear Strength (N/mm)
0%	50	5000	15
10%	52	5500	16
20%	54	6000	17
30%	56	6500	18
40%	58	7000	19
50%	60	7500	20
60%	62	8000	21
70%	64	8500	22
80%	66	9000	23
90%	68	9500	24
100%	70	10000	25

On the physical level, the microstructure characteristics of biomass materials derived from coffee grounds are also very important for the performance change of water-based synthetic leather. The material has a porous microstructure and a large specific surface area. When it is dispersed in water-borne synthetic leather system, these pores can adsorb polymer molecules, increase the interaction between molecules and play the role of physical cross-linking points. Its larger specific surface area increases the contact area between coffee grounds-derived biomass materials and polymer, and enhances the van der Waals force between them. This kind of physical action is like “molecular anchor”, which anchors polymer molecules tightly and limits the relative sliding of molecular chains, thus improving the overall strength and stability of waterborne synthetic leather.

The distribution of biomass materials derived from coffee grounds in water-borne synthetic leather also affects the mechanism. In an ideal state, the material can be uniformly dispersed in the matrix of waterborne synthetic leather, forming a microscopic “reinforcement network”. In this network structure, stress can be transmitted and dispersed more effectively in the material. When the water-based synthetic leather is subjected to external force, the biomass materials derived from coffee grounds is used as the stress concentration point, which diffuses the stress to the surrounding polymer matrix, thus avoiding the material damage caused by excessive stress concentration locally. This stress dispersion mechanism is similar to the reinforcing phase action in composite materials, which enables water-borne synthetic leather to maintain structural integrity and improve its deformation resistance and durability when subjected to external forces.

5. Conclusions

In this study, the application and mechanism of biomass materials derived from coffee grounds in waterborne synthetic leather were deeply discussed. As a waste produced in the coffee industry, coffee grounds are transformed into derivative biomass materials and applied to water-based synthetic leather, which is an important measure to realize resource recycling and green development of the industry. In terms of characteristics, biomass materials derived from coffee grounds has unique physical, chemical and biological characteristics through a specific preparation process, which lays a foundation for its application in water-based synthetic leather. Its porous structure, active functional groups and biocompatibility make it possible to improve the properties of waterborne synthetic leather from the perspectives of physical, chemical and application adaptability. In terms of application, whether it is used as additive, surface coating, or composite fiber combined with water-based synthetic leather, it shows good results. It not only enhances the mechanical properties and improves the surface properties of waterborne synthetic leather, but also endows it with new functional characteristics, which greatly broadens the application field of waterborne synthetic leather. On the mechanism level, the reaction of chemically active groups forms a stable cross-linked network, and the physical porous structure interacts with a larger specific surface area, and the stress dispersion is realized by uniform dispersion, which synergistically improves the properties of waterborne synthetic leather in many aspects.

To sum up, biomass materials derived from coffee grounds has great application potential in water-based synthetic leather, which is expected to promote the development of water-based synthetic leather industry in the direction of green and high performance. In the future, the interaction mechanism between this material and waterborne synthetic leather can be further studied, and the application process can be optimized to achieve wider industrial application and better environmental benefits.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Funding

This work was supported by “Preparation and Performance Study of High-Performance Titanium Dioxide/Polyurethane Composite Membranes” (S202510352053), a 2025 Undergraduate Innovation and Entrepreneurship Training Program Project of Lishui University.

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