

Study on Film-forming Mechanism of Waterborne Polyurethane Resin in Environmental Protection Artificial Leather

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Abstract:

Due to the increasing awareness of environmental protection among people and the gradual improvement of laws, the demand for environmentally friendly synthetic leather has grown accordingly. Under such demand, water-based polyurethane resin has attracted attention in its preparation due to its green and environmentally friendly characteristics. This article focuses on the film-forming mechanism of waterborne polyurethane resin in environmentally friendly artificial leather. Based on the theoretical analysis and the exploration of various stages and influencing factors in the film-forming process, the film-forming process of waterborne polyurethane resin in the preparation of environmentally friendly artificial leather is expounded in detail. At the same time, it is clear that the structure of the resin itself, such as molecular weight and functional groups, environmental factors, such as temperature, humidity and additives, have significant effects on the film formation. The research results provide theoretical support for further understanding the film-forming mechanism, help to optimize the preparation process of environmental-friendly artificial leather, and have great significance for promoting the development of environmental-friendly artificial leather industry and preparing products with better performance.

Keywords:

Waterborne Polyurethane Resin, Environment-friendly Artificial Leather, Film Forming Mechanism, Influencing Factors, Film Forming Process

1. Introduction

With the continuous improvement of social environmental awareness and the increasingly strict environmental protection laws and regulations, traditional artificial leather is gradually unable to meet the market demand because of the pollution problems in the production process and the products themselves [1]. In this context,

the environment-friendly artificial leather came into being and became a new direction for the development of artificial leather industry [2]. Waterborne polyurethane resin, as a kind of green and environment-friendly polymer material, plays an important role in the preparation of environment-friendly artificial leather with its excellent properties. Waterborne polyurethane resin takes water as the dispersion medium, and compared with traditional organic solvent-based polyurethane, it has many advantages, such as non-toxic, non-flammable and less pollution, and meets the requirements of modern society for environmental protection materials [3]. In the field of environmental protection artificial leather production, waterborne polyurethane resin not only can effectively reduce the environmental pollution in the production process, but also can improve the performance of the product, so it has been widely concerned [4].

It is of great significance to study the film-forming mechanism of waterborne polyurethane resin in environmental protection artificial leather. Theoretically, this study is helpful to improve the theoretical system of polymer film formation and enrich the understanding of intermolecular interaction and phase transition of polymers [5]. From a practical point of view, clarifying the film-forming mechanism can provide scientific basis for optimizing the preparation process of environmentally-friendly artificial leather, and guide R&D personnel to prepare environmentally-friendly artificial leather products with better performance by adjusting the formula and process conditions to meet the market demand for high-quality, green and environmentally-friendly materials [6]. At present, there are still some shortcomings in the study of film-forming mechanism of waterborne polyurethane resin in environmental protection artificial leather [7]. On the one hand, some studies only stay on the observation of superficial phenomena, and lack of in-depth exploration of the mechanism of molecular changes in the process of film formation. On the other hand, the research on the film-forming mechanism under the combined action of various factors is not systematic and comprehensive enough, and it is difficult to accurately grasp the synergistic or antagonistic effects among various factors.

In view of this, the purpose of this study is to deeply analyze the film-forming mechanism of waterborne polyurethane resin in environmentally friendly artificial leather. Through the combination of theoretical analysis and experimental verification, the physical and chemical changes, intermolecular interactions and various factors affecting film formation during film formation were systematically studied in order to provide more solid support for the development of environmentally friendly artificial leather.

2. Waterborne Polyurethane Resin and the Theory of Environmental Protection Artificial Leather

Waterborne polyurethane resin is a kind of high molecular polymer containing carbamate groups in its molecular structure, and water is used as the dispersion medium. Structurally, its molecule consists of soft segment and hard segment. The soft segment is usually composed of oligomer polyol, which gives the resin flexibility and low temperature performance; The hard segment is formed by the reaction of diisocyanate and chain extender, which provides hardness, strength and heat resistance. According to different ionic types, waterborne polyurethane resins can be divided into anionic, cationic and nonionic [8]. Among them, anionic waterborne polyurethane resin is the most commonly used, which is prepared by introducing hydrophilic groups such as carboxyl or sulfonic acid groups for ionization.

Waterborne polyurethane resin has obvious advantages in the application of environment-friendly artificial leather. First of all, it uses water as the solvent, which avoids the environmental pollution and health hazards caused by the volatilization of organic solvents [9]. Secondly, waterborne polyurethane resin has good film-forming property, which can form a uniform and continuous film on the surface of the base fabric, giving artificial leather a good appearance and feel. It also has adjustable mechanical properties, and can meet diverse use requirements by adjusting the formula according to different needs. But at the same time, waterborne polyurethane resin also has some potential problems, such as its slow drying speed, which has a certain impact on production efficiency; In some harsh environments, its water resistance and solvent resistance need to be further improved.

3. Film Forming Process of Waterborne Polyurethane Resin in Environment-friendly Artificial Leather

The film-forming process of waterborne polyurethane resin in the preparation of environmentally friendly artificial leather mainly involves dispersion, evaporation, aggregation, melting, and solidification stages [10]. In the dispersion stage, water-based polyurethane resin is evenly dispersed in the system with the help of surfactants and other additives, forming a stable emulsion. The polyurethane particles in this emulsion are relatively independent and evenly distributed in the continuous water phase. At this stage, the stability of emulsion is very important, which is affected by many factors, such as the particle size of polyurethane particles, surface charge density and so on.

With the advance of drying process, the system entered the evaporation stage. At this stage, the water gradually evaporates and the concentration of polyurethane particles in the system increases. At this time, the distance between particles gradually decreases and the probability of collision increases. Under certain drying conditions, when the temperature is set at 50°C and the humidity is 40%, the evaporation rate of water is moderate (as shown in Table 1), which will not cause defects because the particles are too late to arrange because of too fast evaporation, nor will it affect the production efficiency because of too slow evaporation.

Table 1. Comparison of Water Evaporation Rate and Film-Forming Effect under Different Drying Conditions.

Drying Temperature (°C)	Humidity (%)	Water Evaporation Rate (g/h)	Film Smoothness (Grade 1-5, with Grade 5 being the best)	Film Uniformity (Grade 1-5, with Grade 5 being the best)
40	30	3.5	3	3
50	40	4.2	4	4
60	50	5.0	3	3

When water evaporates to a certain extent, the concentration of polyurethane particles reaches a critical value, and the interaction between particles increases, and it begins to enter the aggregation stage. Particles approach each other through Brownian motion, and gradually gather to form loose aggregates under the action of van der Waals force and hydrogen bond. These aggregates initially construct the basic framework of film formation, but at this time the combination between particles is still not close enough.

With the further evaporation of water, the distance between aggregates continues to decrease and enters the fusion stage. At this stage, the molecular segments on the

surface of polyurethane particles began to penetrate and diffuse each other, and the interface between particles gradually disappeared, eventually forming a continuous film. This process needs suitable temperature and time, if the temperature is too high or the time is too long, the performance of the membrane may deteriorate; If the temperature is too low or the time is too short, the film fusion is incomplete, which affects its physical properties. Finally, the film enters the curing stage. During the curing process, further chemical reactions between polyurethane molecules, such as cross-linking reaction, make the molecular chains form a three-dimensional network structure, thus improving the strength, hardness, wear resistance and other properties of the film. At this stage, the type and dosage of curing agent, reaction temperature and time have important influence on the final performance of the membrane.

4. Factors Affecting the Film Formation of Waterborne Polyurethane Resin in Environmentally Friendly Artificial Leather

The film-forming process of waterborne polyurethane resin in environmental protection artificial leather is influenced by many factors such as resin structure, environmental conditions and additives. The first thing is the structural factors of the resin itself. The molecular weight of resin has a significant influence on the film-forming performance. Generally speaking, when the molecular weight is higher, the interaction between molecular chains is enhanced, which is helpful to form a denser and higher-strength film. However, too high molecular weight may lead to an increase in solution viscosity, which is not conducive to uniform coating on the base cloth. As far as the functional groups in the molecular structure are concerned, such as carboxyl, hydroxyl and other hydrophilic functional groups, their content and distribution will change the hydrophilic-lipophilic balance of the resin. When the carboxyl content increases, the hydrophilicity of the resin increases, which is helpful for dispersion in water, but too much may reduce the water resistance of the film. The different reactivity of different functional groups will also affect the formation of cross-linked structure during curing, thus affecting the final properties of the film. See Table 2 and Table 3 for details. It can be seen from the table that with the increase of carboxyl group content from 1% to 3%, the water-resistant time of the membrane decreased from 24 hours to 12 hours, which clearly reflected the negative effect of functional group content on water resistance.

Table 2. Impact of Different Functional Group Contents on the Water Resistance of Film-Formed from Waterborne Polyurethane Resin.

Carboxyl Group Content (%)	Hydroxyl Group Content (%)	Film Water Resistance Time (Hours)
1	5	24
2	5	18
3	5	12

Table 3. Impact of Resin's Own Structural Factors on Film-Forming Performance

Resin's Own Structural Factors	Specific Parameter Performance	Positive Impact on Film-Forming Performance	Negative Impact on Film-Forming Performance
Molecular Weight	When the value is high	The intermolecular forces are enhanced, promoting the formation of a dense and high-strength film	The solution viscosity increases, making it difficult to uniformly coat on the base fabric

Functional Group (Taking carboxyl group as an example)	When the content increases	Hydrophilicity is enhanced, facilitating dispersion in water	Water resistance decreases
Functional Group (Taking hydroxyl group as an example)	When the content increases	Participates in cross-linking reactions, improving the film's cohesion	When excessive, it may change the degree of cross-linking and affect the film's flexibility

Environmental factors can not be ignored. Temperature plays a key role in the process of film formation. At the initial stage of drying, suitable temperature can accelerate the evaporation of water and promote the aggregation and fusion of particles. However, when the temperature is too high, the water evaporates too quickly, and the particles can't be arranged in order, which easily leads to defects on the membrane surface. If the temperature is too low, the evaporation of water will be slow, and the film forming time will be prolonged, which may even make the film unable to completely cure. Humidity also has an important influence on film formation. High humidity environment will slow down the evaporation rate of water, make the system in a high water content state for a long time, and affect the interaction between particles and the film formation process. Under the condition of high humidity, the film surface may be sticky and the strength is insufficient.

Additives also play a unique role in the film formation of waterborne polyurethane resin. Plasticizer can reduce the force between resin molecules and improve the flexibility and plasticity of the film. However, the excessive addition of plasticizer will lead to the decrease of mechanical properties of the film, such as the decrease of tensile strength. Curing agent is very important to the formation of cross-linking structure of membrane, and its type and dosage directly determine the degree of cross-linking. Proper curing agent can make the film form a stable three-dimensional network structure and improve the hardness, wear resistance and chemical resistance of the film. However, if the curing agent is used too much, the film may become brittle and hard, and lose its flexibility. In addition, additives such as leveling agent and defoamer, although used in small amounts, play an indispensable role in improving the surface quality of the membrane, such as flatness and eliminating bubbles.

5. Conclusions

In this study, the film-forming mechanism of waterborne polyurethane resin in environmental protection artificial leather was deeply discussed, and a series of valuable results were obtained. In the film-forming process, waterborne polyurethane resin has gone through many stages such as dispersion, evaporation, aggregation, fusion and curing from emulsion state with water as dispersion medium, and finally formed a continuous and stable film. In this process, the evaporation rate of water affects the interaction and arrangement of particles, and then determines the microstructure and macroscopic properties of the film. The factors affecting film formation are complex and diverse. In terms of the structure of the resin itself, the molecular weight and the type and content of functional groups fundamentally determine the basic properties of the film, such as strength, flexibility and water resistance.

These research results have important guiding significance for the preparation of environmentally friendly artificial leather. It provides a solid theoretical basis for

optimizing the preparation process, and producers can accurately adjust the formula and process parameters according to these conclusions, thus improving production efficiency and product quality. At the same time, it is helpful to develop environmentally-friendly artificial leather products with better performance and meet the market demand for high-quality, environmentally-friendly materials. With the further research, it is expected to make more breakthroughs in the modification of waterborne polyurethane resin and the optimization of film-forming process in the future, and promote the development of environmentally friendly artificial leather industry in a greener and more efficient direction.

Conflicts of Interest

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

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