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Research paper

Design of Next-Generation 4D Mask Pack

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Abstract

This study identified the development status and material development technology of mask packs in the beauty industry, which is recently receiving a global attention and designed a 4D mask pack enriched with hydrogels to meet the demand of the new era. This study also presented a next-generation mask model that has superior adhesion capability to facial curves. It was developed by applying hydrogels, a soft material similar to the extracellular matrix, to control mechanical properties of the mask pack for appropriate stiffness and swelling ratio. This development technology is considered to be a great help in creating a new convergence field of future beauty industry.

Keywords: *Mask packs, Facial mask, 4D mask, Hydrogel, Adhesion*

1. Introduction

The market of skincare and mask pack products that utilize cosmetotextile technology is recently expanding as the income level rises and there is a growing interest in healthcare, skincare and appearance management [1]. The importance of functional materials in cosmetics was emphasized in the existing mask pack market. But, recently, cutting-edge technologies are applied resulting from the convergence of functional materials and new fiber polymer material technology to contain and control functional materials and skin transmitters [2].

Mask pack enables an effective provision of various nutrients to the skin and thus a convenient provision of various effects, such as moisturizing, whitening, anti-aging and skin waste elimination, for consumers. This consumer trend contributes to the recent rapid expansion of the mask pack market, and its continuous growth is expected. The global mask pack market is expected to grow at a compound annual growth rate (CAGR) of 8.7% during the period from 2016 to 2024, and the value of the sheet mask pack market is estimated to reach USD 337 million (approx. KRW 400 billion 457.1 million) [3][4]. Against this backdrop, more Korean and overseas research groups conduct research on mask packs. Currently, materials often used to make mask pack include nonwoven fabrics, hydrogels, bio-cellulose and cotton. Among these materials, bio-cellulose is considered the most popular because it is a natural material and has superior adhesion capability for tightening facial contours. Current mask packs have the same active ingredients penetrate the entire facial skin, and some of them come in a slit-patch type or an upper and lower separated type for care on different parts. But these mask packs are not suitable to facial skin that has different characteristics for different parts [5]. Therefore, the next-generation mask pack suggested in this study is expected to become one of the key leading technologies in future beauty industry. And further successful outcomes will have potential academic and practical values and have a great effect on the development in the K-beauty industry

2. Mask Sheet Development Status by Phase and Applied Technologies

A mask pack, or a facial mask, is a type of cosmetics that provides various nutrients and moisture to the skin through a matrix or a sheet designed to fit the facial shape. There are various types of mask pack sheets coated with beauty ingredients [6].

In terms of mask sheet formulations, mask packs are categorized into three types: the peel-off/wash-off type (1st generation); the sheet type (2nd generation); and the hydrogel type (3rd generation).

As for 1st generation mask packs, natural ingredients were used and basically, the mask packs were applied on the face and then washed off. Such ingredients as gold, fruit, plants and grain were often used. And 2nd generation mask packs, called sheet masks, have emerged in the 1990s. At the beginning, sheet mask packs were made of nonwoven fabrics that were coated with formulations in a liquid state, such as toner, and later, sheet-type mask packs made of cotton fabrics were developed for better absorption and adhesion [7]. Thin nonwoven fabrics were the preferred form of nonwoven fabrics for mask packs. Thin nonwoven fabrics were cut into a face shape, one side of the sheet was coated with beauty ingredients and then the coated sheet was hermetically sealed. Disposable mask packs made this way were convenient to use and had good texture due to superior adhesion [8]. But nonwoven fabrics are often added with synthetic polymers, and nonwoven fabrics added with synthetic polymers become stiff, do not have good texture and are not skin-friendly. In the case of a formulation that induces a continuous absorption of cosmetic liquid through the use of nonwoven fabrics that are soaked in additives, such as cosmetic liquid, the adhesion to the skin is weak and there is a high possibility of skin irritation due to the contact with extremely high concentrated beauty ingredients at the beginning. In addition, all moisture evaporates in 10 to 15 minutes and the mask pack sheet dries up and falls off the face. And a considerable amount of adhesion-improving moisturizer, such as glycerin, should be added to prevent cosmetic liquid from slipping down. If used in excess amount, the adhesion-improving moisturizer can rather deprive moisture from the skin and inhibit skin respiration, making the skin rough and enlarging pores. There are methods to improve these weaknesses [9]. For example, the opposite side of the sheet adhering to the skin can be coated with synthetic resins, or nonwoven fabric sheets of mask packs can be made in a multi-layer construction that include a functional film or sheet, for higher strength and water absorption. And 3rd-generation mask packs were hydrogel mask packs that were developed using cotton and natural gums in 2004. There was a 2.5-generation mask pack developed in 2007 between 2nd and 3rd generation mask packs. It was a bio-cellulose mask pack developed using natural materials. Due to the manufacturing characteristics of bio-cellulose, it produces a lot of waste water and pollutants thus; bio-cellulose is now imported from abroad. Although it supplements weaknesses of mask packs made of nonwoven fabrics, such as heaviness, slipping-down and weak adhesion, a bio-cellulose mask pack gets dry on the surface in a short time. Next, 4th-generation mask packs were developed to prevent contamination by microorganisms, which was a weakness of bio-cellulose mask packs [10].

Dried bio-cellulose mask packs, 5th-generation mask packs, show more environmentally-friendly technology through natural sheets made by cultivating microorganisms. Although 5th-generation mask packs are considered an innovative new material, their production process is tricky and their production period is long. This leads to low productivity and high production costs. Other various technologies are presented, such as a microneedle that improves the delivery efficiency of active ingredients; a technology that increases the penetration of mask packs by applying a electrospinning method to nano-nonwoven fabrics; a 3D printer and the Internet of Things (IoT); a market of smart beauty that uses micro current; a technology that combines facial beauty products with those of other body parts; and phase change materials that were developed from the existing hydrogels and bio-cellulose. As seen here, mask sheets have changed throughout different eras and at present, cutting-edge technologies are introduced. Therefore, it is a time that a new evolving technology in response to the 4th industrial age is required.

3. Designing 4D Mask Pack Using Hydrogels

As seen above, technologies from various fields have been adopted to develop beauty mask sheets.

Recently, there have been many research activities on bio-robots to embody various living organisms' mechanisms by combining biomaterials, such as living cells, with soft materials that are flexible but have sufficient strength. The most important factor here is the binding force between the biomaterial used and the soft material [11]. Hydrogels are one of the materials that can best imitate such properties. Hydrogels were once often used as mask pack materials, but they are hardly used now since their weaknesses were not improved. In general, the moisture content of hydrogels can be as much as 10% to 2000% of their weight. They do not dissolve in water and have a three-dimensional hydrophilic polymer reticulum that is structurally stable with little fluidity due to external traceability [12]. After swelling in an aqueous solution, they have thermodynamically stable mechanical-physical properties in a transitional form between liquid and solid. In addition, the swelling degree of the hydrogel can be controlled according to the chemical structure of the polymer, the crosslinking density between the hydrophilic group and the polymer chain, and thus it is possible to produce hydrogels having various shapes and properties depending on the constitution and manufacturing method. And the swelling degree of hydrogels can be controlled according to the chemical structure of polymers, the crosslink density between the hydrophilic group and the polymer chain [13]. This makes it possible to produce hydrogels in various forms and of various characteristics according to components and production methods. Hydrogels are widely applied in various fields such as tissue engineering, drug delivery and food industry because hydrogel materials are similar to extracellular matrix in vivo in terms of structure and its properties. Mechanical properties of hydrogels can be controlled for appropriate stiffness and swelling ratio by adjusting the type, concentration and crosslink degree of polymers used. Therefore, if hydrogels having different swelling degrees according to the temperature are produced in multi layers, the multilayered hydrogels will have a curvature due to self-folding at a specific temperature (skin temperature). As shown in Fig. 1 [13], hydrogels composed of two layers having different swelling ratios show a folding phenomenon at a specific temperature, and self-folding occurs in one direction due to their different thermosensitivities. This way, hydrogels have a curvature. As shown in Fig. 2 [13], it is possible to produce customized 4D mask packs that can self-transform according to curves of each facial part by introducing a design technology to predict and control individual curvature radii that uses the bimetallic strip curvature equation when the two layers with different thermosensitivities form a curvature (1).

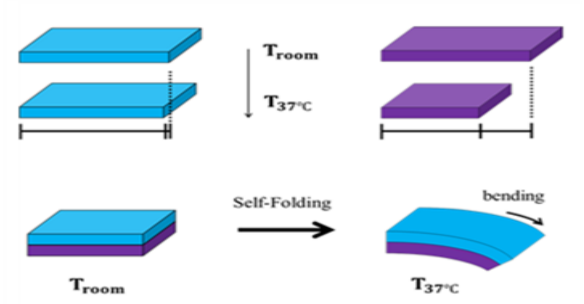

Fig. 1: The multi-layered hydrogels model with temperature-sensitive molecules. T_{room} = room temperature, $T_{37℃}$ = 37℃ [13].

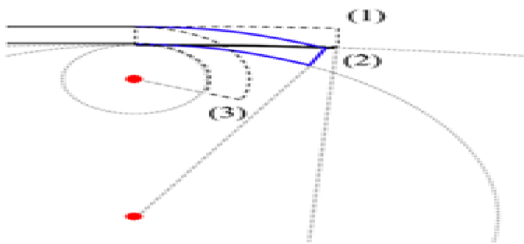

Fig. 2: Curvatures of the multi-layered hydrogels. (1-3) = A self-folded hydrogels [13].

These 4D mask packs are expected to have dramatically improved functionality because they actively respond to facial curve conditions to improve the adhesion to the skin and the penetration of active ingredients into the skin. These 4D mask packs maintain a flat state at room temperature. When they are attached to the skin, a self-folding phenomenon occurs according to different thermosensitivities of the two layers and they tightly adhere to the curved facial surfaces of each person.

$$r = \frac{E_1{}^2 t_1{}^4 + 4E_1E_2t_1{}^3t_2 + 6E_1E_2t^2t^2 + 4E_1E_2t_1t_2{}^3 + E_1{}^2t_2{}^4}{6E_1E_2(t_1+t_2)t_1t_2\Delta\varepsilon} \quad (1)$$

Consequently, they can be the next-generation mask packs that can improve the penetration of active ingredients into the skin, providing customers with the maximum satisfaction in terms of adhesion and flexibility [14]. In the second proposal model, the functionality of mask packs can be improved remarkably by compartmentalizing the facial surface and delivering the most suitable active ingredients to each facial part in a “simultaneous and customized” manner. In this production method, multi compartments are designed to control the self-folding curvature of an individual layer of multilayered hydrogels and then, the curvature value of individual compartment (pixel) are calculated through 3D printing (using DLP printers) to produce multilayered hydrogels that have the calculated curvature values [15]. This method requires standardization techniques regarding the number and position of compartments, the thickness of multilayered hydrogels, etc. The multicompartmentalized hydrogels can fill the inside of each independent compartment with the most suitable active ingredients, thus producing new-concept mask packs capable of delivering the customized active ingredients to each facial part. Because the mask packs are in a multilayer structure, the layer contacting the skin can be designed to deliver active ingredients, while the outside layer can be designed to have increased moisturizing power to help reduce skin irritation through stratum corneum hydration, effectively inducing the skin absorption of functional ingredients.

4. Conclusion

The current situation requires change, technology and development. At present, the mask pack market is growing rapidly and is expected to continue to grow in future. At this time, the role of sheets, a carrier of active ingredients, is very important. And customers' need for new mask pack materials continue to increase, particularly, in terms of skin adhesion, absorption and skin penetration among different roles of mask pack sheets. As mentioned above, materials currently used need to be improved a lot in several aspects and it is difficult for them to survive in the market. There is an urgent need to develop differentiated body-friendly materials with safe process and production as well as independent production technology in order to meet customer needs and respond to a changing market. Therefore, the 4D mask pack models suggested in this study are considered to be a great help in developing new mask sheet materials.

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