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ECOLOGICAL COSMETIC PACKAGING: USE OF BIODEGRADABLE POLYMERS

EKOLOGICZNE OPAKOWANIA KOSMETYCZNE: WYKORZYSTANIE BIODEGRADOWALNYCH POLIMERÓW

***Summary**: Traditional plastic packaging used in the cosmetics industry constitutes a significant burden on the environment due to its limited recyclability and long degradation time. In response to this problem, an alternative solution was developed in the form of biodegradable polymer packaging. This work presents the process of creating a safe and functional packaging for cosmetic masses, which is biodegradable under industrial composting conditions. The research included the development of an appropriate polymer composition, analysis of its mechanical and barrier properties, assessment of biodegradability and safety in contact with cosmetic products. Additionally, tests were carried out to optimize the production process and a series of packaging meeting the appropriate requirements were developed. The effect of the work carried out was to obtain a material with functional parameters that also meets environmental standards. The effectiveness of the developed solution was confirmed by obtaining appropriate certificates and a patent for the invention, which proves the innovativeness and implementation potential of the new type of biodegradable cosmetic packaging.*

***Keywords**: polylactide, biodegradation, mechanical properties, cosmetic packaging*

Streszczenie: Tradycyjne opakowania z tworzyw sztucznych stosowane w przemyśle kosmetycznym stanowią istotne obciążenie dla środowiska ze względu na ich ograniczoną możliwość recyklingu i długi czas degradacji. W odpowiedzi na ten problem opracowano alternatywne rozwiązanie w postaci biodegradowalnych opakowań polimerowych. Niniejsza praca przedstawia proces tworzenia bezpiecznego i funkcjonalnego opakowania na masy kosmetyczne, które ulega biodegradacji w warunkach kompostowania przemysłowego. Badania obejmowały opracowanie odpowiedniej kompozycji polimerowej, analizę jej właściwości mechanicznych i barierowych, ocenę biodegradowalności oraz bezpieczeństwa w kontakcie z produktami kosmetycznymi. Dodatkowo, przeprowadzono testy nad optymalizacją procesu produkcji oraz opracowano serię opakowań spełniających odpowiedzenie wymagania. Efektem przeprowadzonych prac było uzyskanie materiału o parametrach użytkowych, który jednocześnie spełnia normy środowiskowe. Skuteczność opracowanego rozwiązania potwierdzono poprzez uzyskanie stosownych certyfikatów oraz patentu na wynalazek, co dowodzi innowacyjności i potencjału wdrożeniowego nowego typu biodegradowalnych opakowań kosmetycznych.

Słowa kluczowe: polilaktyd, biodegradacja, właściwości mechaniczne, opakowania kosmetyczne

Introduction

Polymer packaging plays an extremely important role in the cosmetics industry. It is used not only to store and protect products, but also plays a key marketing role, influencing consumer purchasing decisions. The modern cosmetics industry strives to use materials that combine high aesthetics and durability with ecological aspects. Traditional synthetic polymers, although they provide excellent protection for cosmetics, pose a significant burden on the environment, especially as post-consumer waste [1–5].

In the face of growing ecological awareness and restrictive legal regulations, more and more attention are being paid to biodegradable polymeric materials [6-10]. Their use in cosmetic packaging is a compromise between durability and protection of the product and reduction of the negative impact on the environment after the end of the packaging life cycle. Among biodegradable polymers, polylactide (PLA) occupies a special place, being one of the most promising materials in this field [11–13].

Polylactic acid (PLA) is a biodegradable polymer obtained from renewable raw materials such as corn starch, sugar cane or sugar beet. It is one of the most promising biopolymers, used in many industries, including cosmetic packaging, medicine, food and textiles [14–16]. It decomposes in industrial composting conditions, transforming into water, carbon dioxide and biomass, creating a closed circle, as it is produced from plants, which reduces the dependence on fossil fuels. It does not contain toxic substances and is approved for contact with food and cosmetics. It can be used to produce elegant, transparent packaging with high visual quality. It shows strength similar to traditional plastics, although it is more brittle [17–18].

Polylactide (PLA) is naturally resistant to fats and oils, making it an attractive material for use in the cosmetics and food industries. However, its barrier against the penetration of chemicals, both from the inside of the package to the outside and vice versa, is limited [19–22]. In order to improve the barrier properties of PLA, various modification methods are used, such as: addition of fillers and nanofillers, coating with protective layers, chemical modifications or co-polymerization by introducing additional monomers, increasing its hydrophobicity of PLA, reducing the penetration of moisture and organic substances. Such treatments significantly worsen its biodegradability [23–25]. It is necessary to find a compromise between the durability of the packaging and its degradation after the end of its use. With appropriate modifications, PLA can achieve properties similar to conventional plastics, while maintaining biodegradability and compliance with ecological standards.

The purpose of the work was to develop a material for cosmetic packaging that is biodegradable under industrial composting conditions. This was a significant challenge due to the specific and difficult to achieve criteria both as packaging for the cosmetics industry, but also maintaining the biodegradability of such a material.

Materials and research methodology

Several types of polylactides with different parameters and properties from NatureWorks were used for preliminary studies. Other biodegradable polymer materials were used as modifiers in preliminary studies. Among others, the group of polyhydroxyalkanoates (PHA), belonging to the group of aliphatic polyesters, built from one hundred to several thousand hydroxy acid residues. They are characterized by a large variety of monomer structures. They are produced by bacteria in the fermentation process of sugars or lipids as a reserve material. The prepared mixtures of these two polymers were not problematic in the processing process, but they did not meet the requirements related to the migration of the reference substance from the packaging to the material. Such composites would not be a barrier for cosmetic masses [26-27].

Similar tests were performed with PHBV Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) is a polyhydroxyalkanoate type polymer. It is a biodegradable, non-toxic, biocompatible polymer produced naturally by bacteria and a good alternative to many non-biodegradable synthetic polymers. It is a thermoplastic linear aliphatic polyester. It is obtained by copolymerization of 3-hydroxybutanoic acid and 3-hydroxypentanoic acid. PHBV is used in specialist packaging, orthopedic devices and in controlled drug release. PHBV undergoes bacterial degradation in the environment [28-30].

To optimize the functional properties of polylactide (PLA) and maintain its biodegradability, calcium carbonate ($CaCO_3$) was added as a filler. Calcium carbonate is widely used in traditional polymer materials due to its numerous beneficial properties, such as improved processability, dimensional stability and barrier properties of the material [31-34]. Moreover, its use allows for reducing production costs, which is an important aspect when implementing biodegradable polymers as alternatives in the packaging industry. Ready-made calcium carbonate concentrates are available on the market in the form of concentrates (masterbatches), which can be easily dosed to the polymer during processing. However, in this case it was necessary to use calcium carbonate in the form of a powder with a precisely selected structure. The key aspect was to control the size and shape of the particles to ensure their uniform dispersion in the PLA matrix, which prevents aggregation and negative impact on the mechanical and optical properties of the material [35-38].

Additionally, the selection of the appropriate $CaCO_3$ concentration was important from the point of view of maintaining the biodegradability of the entire system. Excessive amounts of non-degradable filler could limit the rate of material decomposition in composting conditions. The optimal weight share of calcium carbonate allowed for maintaining a balance between improving the functionality of the packaging and its biodegradability at the end of its life cycle. Calcium carbonate from OMNIA (Switzerland) was used in this work [39-40].

The tests carried out with direct introduction of the filler into the plastic on an injection molding machine equipped with a feeder did not cause any problems, because the maximum filling was 10% wt. However, tests of the material structure showed uneven distribution of particles. Therefore, it was necessary to prepare the material in advance on an extruder. For this purpose, a twin-screw extruder was used [41].

The decisive factor here was the research on ready-made containers with cosmetic mass. Despite meeting several criteria, there was still a problem with the migration of the reference substance (cosmetic mass) into the material. A slight loss of mass was also observed, but definitely smaller than in the previously discussed cases.

The solution that gave positive results was the use of an aromatic carbodiimide-based additive in PLA with calcium carbonate [41-42]. Carbodiimides are a group of organic compounds containing a characteristic functional group –N=C=N–, which are widely used as condensing agents in coupling reactions, e.g. in peptide synthesis and in polymer modification. Their unique chemical properties, including the ability to bind water molecules, mean that they have been used as stabilizers in biodegradable materials, where controlling interactions with water is crucial [43-45].

The use of aromatic carbodiimides in this system allowed for the optimization of the compromise between the durability and biodegradability of the material. On the one hand, the resistance to external factors was increased, which is important for the functionality of cosmetic packaging, and on the other hand, the possibility of degradation in appropriate industrial composting conditions was preserved. Additionally, an important aspect was the adjustment of the amount and type of carbodiimide used. An excessive amount could lead to a significant reduction in biodegradation, making the material less ecological, while too low an additive level would not provide sufficient protection against moisture. Therefore, it was necessary to select the appropriate concentration, which would allow for effective protection of the polymer structure, while not interfering with its ability to biodegrade after the end of its life cycle.

All PLA additives were introduced in the twin-screw extrusion process. This method of production guaranteed obtaining a homogeneous material. Carbodiimide with the trade name Stabaxol P110, available in powder form, was used in the tests as well as in later works [46-47].

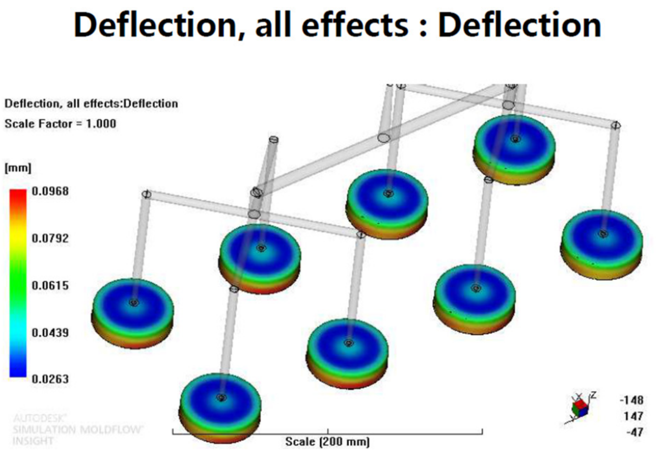
Ultimately, after optimizing the individual components, we managed to develop a PLA-based material that underwent tests both in terms of mechanical properties and in terms of assessing the process of interaction between the cosmetic mass and the packaging.

Construction of tools (injection molds) for complete packaging

In parallel with the work on refining the composition of the polymer composition, work was underway on the design of tools and injection molds for the production of complete packaging in the form of a jar with capacities from 0.25 dcm^3 to 0.50 dcm^3. It was necessary to design injection molds for the jar and for the lid with a thread. The problem to be solved was to determine the compatibility of the jar and lid threads. It resulted from material shrinkage.

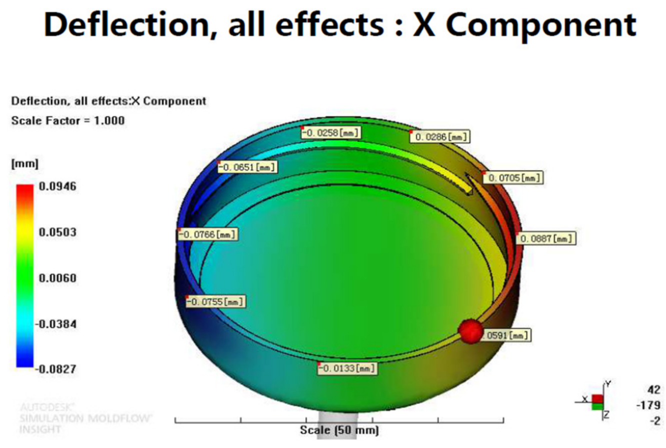
In order to eliminate defects at the design stage, MoldFow software was used. Figures 1 to 5 show the subsequent stages of analysis of the results obtained during simulation.

The obtained simulation results taken into account in the modeling of the injection molding process were a valuable hint for designers and technologists during the process design. They also allowed for the selection of optimal process parameters to



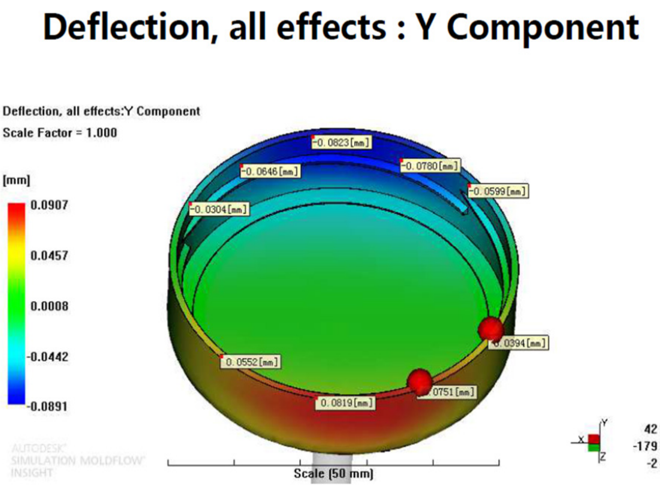
The deflection include uniform shrinkage.	
The scale of deflection	1
Total deflection value (mm)	0.0968

Fig. 1. Distribution of nests in the injection mold



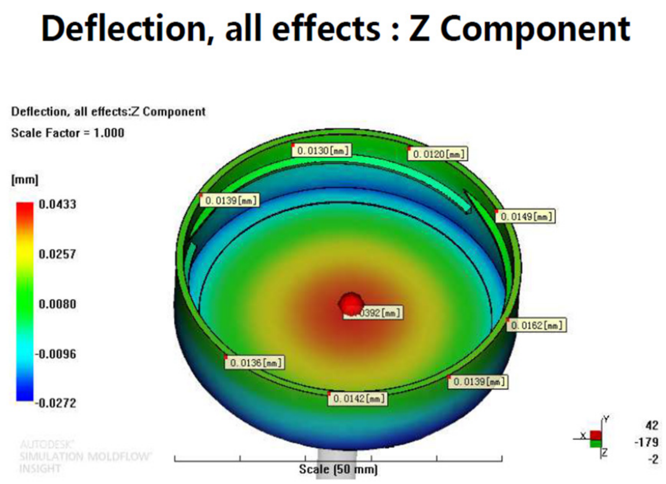
The deflection include uniform shrinkage.	
The scale of deflection	1
The deflection value of X component (mm)	-0.08~0.09

Fig. 2. Process simulation



The deflection include uniform shrinkage.	
The scale of deflection	1
The deflection value of Y component (mm)	-0.08~0.09

Fig. 3. Injection simulation, part II



The deflection include uniform shrinkage	
The scale of deflection	1
The deflection value of Z component (mm)	-0.02~0.04

Fig. 4. Injection simulation, part III

obtain the required quality of the part and to reduce the number of attempts to correct the mold and machine parameters. Figures 6 and 7 show photos of the manufactured jar and lid.

Conclusions & Suggestions

Results	Case
Fill status	Good
Range of temperature at the flow front (°C)	161-181
The max. pressure value (Mpa)	95.47
The max. Clamp force value (tonne)	95.77
Weld lines	No
Serious air traps	No
The deflection is normal or not for this product	Yes

Fig. 5. Injection simulation – summary

Fig. 6. Photos of the finished jar and lid

Fig. 7. Complete package

Conclusions

The use of biodegradable polymeric materials, such as polylactide (PLA), is a significant step towards the sustainable development of the cosmetics industry, and in particular for the production of packaging. The combination of high-quality packaging with minimal impact on the environment allows to meet the expectations of both consumers and legal regulators. Despite the challenges related to costs and infrastructure, the dynamic development of this technology gives hope for the widespread implementation of biodegradable packaging in the future. The best recommendation of the conducted work was the confirmation of the properties of the material and packaging through obtained certificates [48, 49] and the patent for the invention No. PL 244616 [50].

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