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"Study on the suitability of Various Materials as Talc Alternatives in Makeup Powder Formulations"

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1. Introduction

Talc has traditionally played a fundamental role in makeup powder formulations, analogous to the role of purified water in skincare products. Talc ($Mg_3Si_4O_{10}(OH)_2$) is an exceptionally soft mineral, possessing a Mohs hardness of 1, and is characterized by its smooth, slippery texture. Furthermore, talc exhibits excellent compressibility, making it an indispensable component in establishing the basic structural integrity of pressed powder formulations.

However, the cosmetics industry is evolving beyond purely aesthetic and functional considerations to prioritize environmental sustainability and health consciousness. While talc offers advantages in terms of cost-effectiveness and ease of formulation, increasing concern in the European and North American markets regarding clean beauty and sustainability has driven efforts to eliminate talc from cosmetic products. Although early studies suggested a potential link between talc in powder makeup products and ovarian cancer [1], subsequent research has demonstrated that cosmetic-grade talc, free from asbestos contamination, does not pose a health risk [2]. Nevertheless, the search for talc alternatives remains an active and growing area within the market.

In this study, we aim to evaluate various raw materials as potential alternatives to talc in powder makeup formulations. To minimize external variables, each candidate material will be fully substituted for talc without additional formulation adjustments to enhance usability. The raw materials selected for evaluation include mica, synthetic fluorphlogopite, sericite, and kaolin—commonly used bulking agents in cosmetic applications.

To assess the stability of the formulations, the prepared samples will be compressed into identical pans under uniform pressure. Stability will be evaluated using a rheometer, one of the most reliable methods for measuring penetration depth to assess hardness and mechanical integrity. Additionally, drop tests will be conducted to further investigate the mechanical robustness of each formulation.

Based on the comprehensive analysis of the collected data, the optimal talc alternative will be identified. Furthermore, the morphological features of talc and the selected alternative raw materials were examined through particle shape observations conducted using optical microscopy.

2. Materials and Methods

2.1. Materials

Talc (7 μm particle size distribution(PSD)) was selected as the reference material, representing a commonly utilized specification in commercial powder makeup formulations. Alternative bulking agents—mica, synthetic fluorphlogopite (synthetic mica), sericite, and kaolin—were chosen based on their widespread use in cosmetic applications. For comparative analysis, raw materials with similar particle size distributions to talc were selected. Additionally, control samples of the same materials with differing PSDs were prepared to evaluate the effect of particle size.

2.2. Particle Size and Morphological Analysis

Particle size distributions (PSD) of talc and alternative raw materials were analyzed using a Mastersizer 3000 particle size analyzer (Malvern Instruments, UK). Each sample was dispersed in distilled water and measured under the instrument's standard operating conditions specific to each material. The morphological characteristics of talc and the alternative raw materials were examined using an Olympus BX23 optical microscope equipped with a TH4-200 halogen lamp(Olympus, Japan). Particle size and shape were observed at a magnification of 1000X to enable detailed analysis of surface morphology and structural features.

2.3. Formulation Preparation

Powder formulations were prepared by incorporating bulking agents and colorants into an Ika Mixer M20 (IKA, Germany), followed by dispersion at 15-second intervals (two cycles). Subsequently, a 5% oil binder was added to the mixture and further dispersed under the same conditions. The specific raw materials and oils used in each formulation are detailed in Table 1.

Table 1. Sample formulations

Main Ingredient	Bulking Agent	Oil Binder
Talc A Mica A Mica B Sericite A Sericite B Synthetic fluorphlogopite A Synthetic fluorphlogopite B Kaolin A Kaolin B	Bulking Agent (Boron Nitride, Silica, Magnesium Stearate)	Caprylic/Capryl Triglyceride

75%	18%	7%

2.4. Compression Process

Prepared formulations were compressed into 43 mm aluminum pans, commonly utilized for powder makeup products. Prior to compression, each formulation was weighed precisely to ensure consistency. Compression was performed using a hydraulic press at 40 bar for 2 seconds. The precise quantity of powder varied depending on its compressibility and is summarized in Table 2. To minimize variability, five replicates per formulation were prepared, and the average weight was calculated.

Table 2. Sample Weight

Sample	Weight
Talc A sample	3.8g
Mica A sample	3.6g
Mica B sample	3.5g
Sericite A sample	4.3g
Sericite B sample	4.0g
Synthetic fluorphlogopite A sample	3.7g
Synthetic fluorphlogopite B sample	3.9g
Kaolin A sample	4.0g
Kaolin B sample	4.0g

2.5. Penetration Depth Measurement

The mechanical hardness of the compressed powders was evaluated by measuring penetration depth using a rheometer (Fudoh, Japan). Measurements were conducted under the following settings: 3 mm spindle, 0.5 mm depth, 2K/20N range, and 30 cm/min testing speed. Each sample was measured three times at the center, and the average values were recorded for analysis.

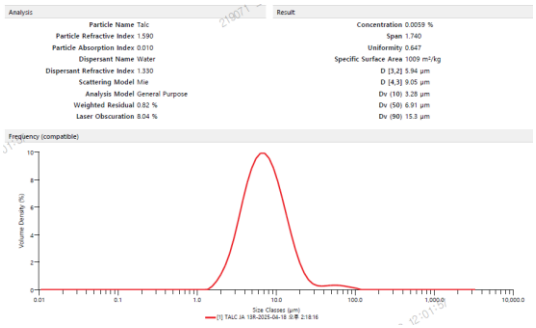
2.6. Drop Test

Mechanical stability was further assessed via drop tests. Compressed formulations, secured within their respective containers, were dropped from a height of 50 cm onto a 1T stainless steel (SUS) plate, three times. Post-drop evaluations included both visual inspection and quantitative assessment, measuring the weight of broken or detached fragments to assess the degree of damage.

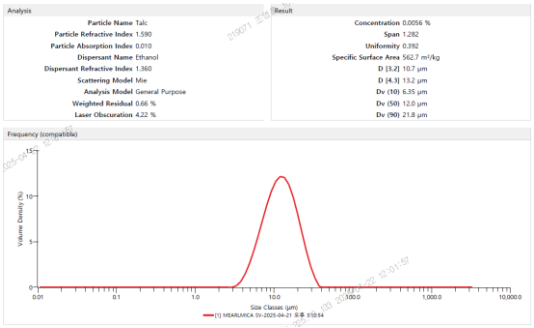
3. Results

3.1. Particle Size Distribution and Morphology

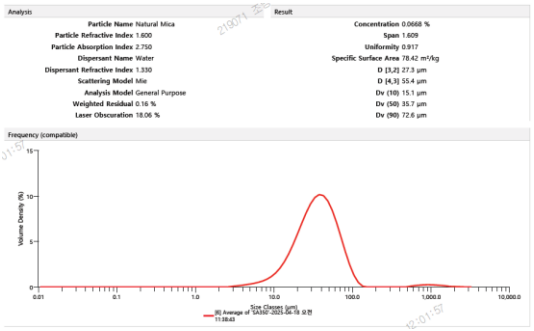
The particle size analysis of the various raw materials considered as alternatives to talc is summarized below.



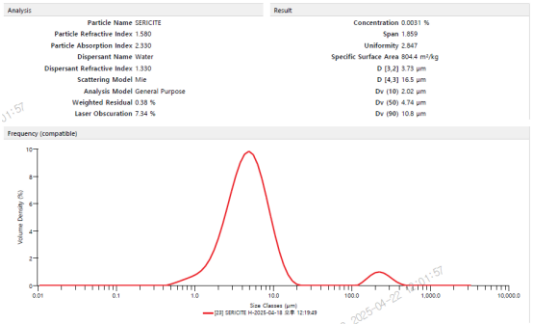
(Talc A)



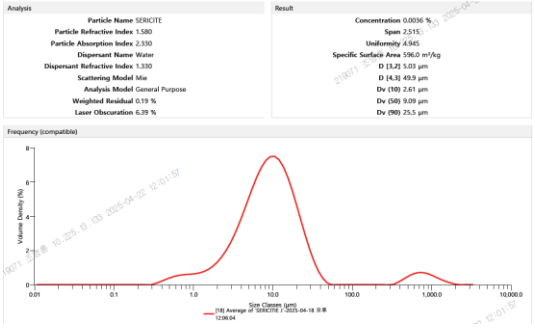
(Mica A)



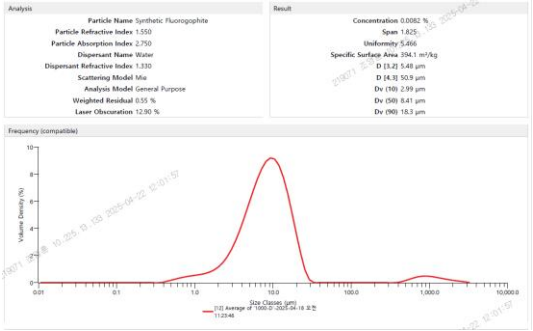
(Mica B)



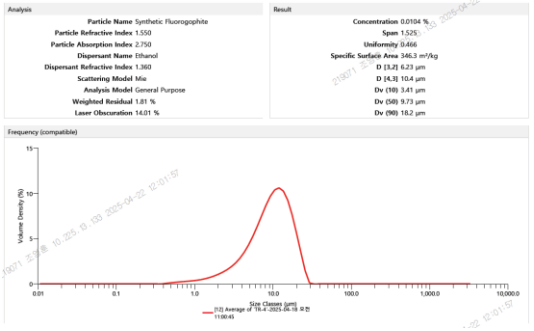
(Sericite A)



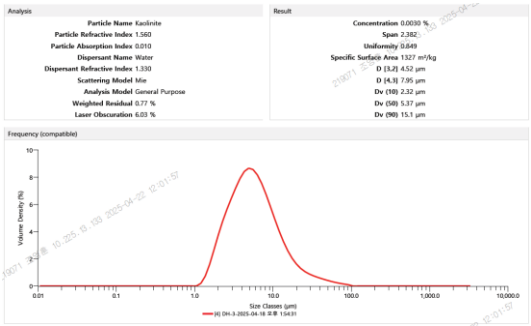
(Sericite B)



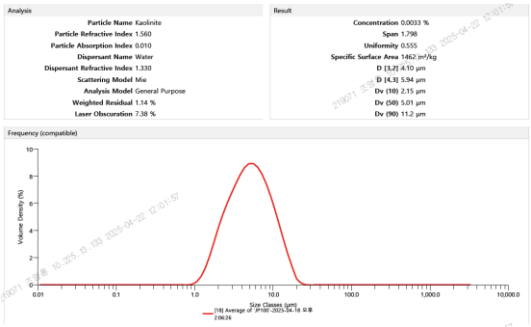
(Synthetic fluorphlogopite A)



(Synthetic fluorphlogopite B)



(Kaolin A)



(Kaolin B)

Figure 1. Particle Size Distribution Charts of Targeted Samples

The reference talc used in this study was a non-coated grade with an approximate d50 value of 7 µm, a specification commonly adopted in commercial makeup formulations. Among the tested materials, synthetic fluorphlogopite B exhibited the most similar particle size distribution to talc, suggesting its potential as a viable substitute based on PSD. To investigate the influence of particle size on formulation properties, two sets of samples—one with a smaller average size and one with a larger average size—were prepared for each of the alternative materials (mica, synthetic fluorphlogopite, sericite, and kaolin). This allowed for evaluation of how particle size variation impacts formulation stability and structure.

Morphological characteristics of each material were analyzed using an Olympus BX23 optical microscope equipped with a TH4-200 halogen lamp, with observations conducted at 1000× magnification.

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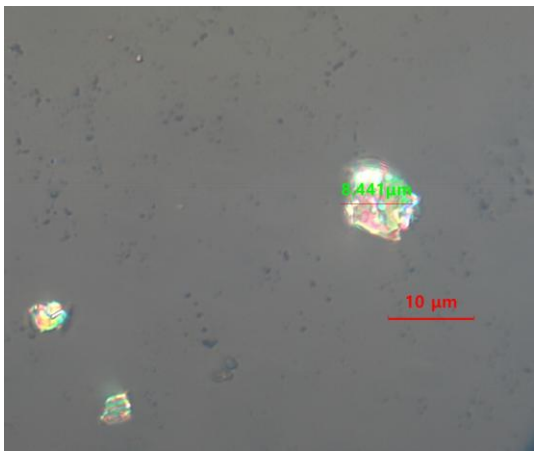
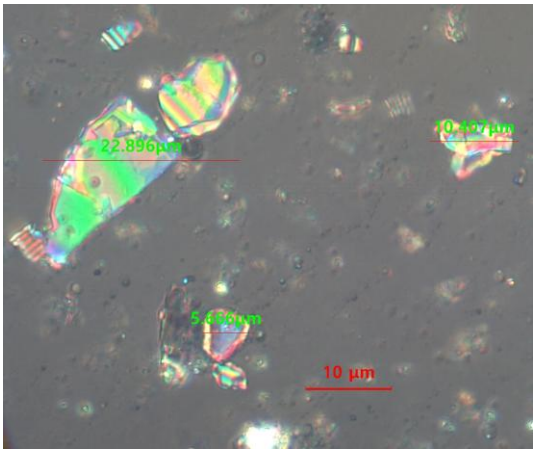
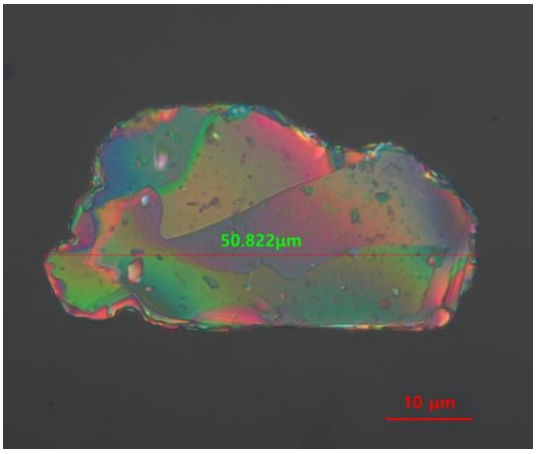


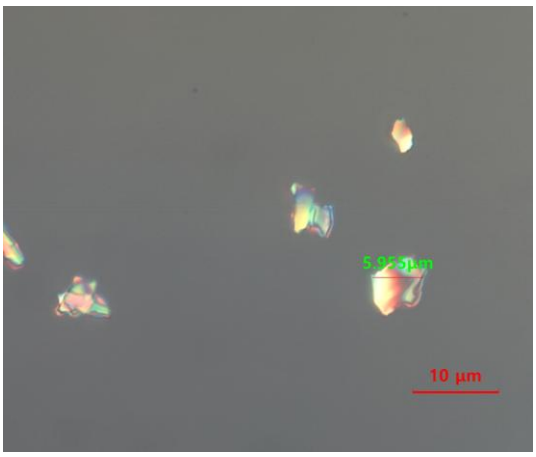
(Talc A)



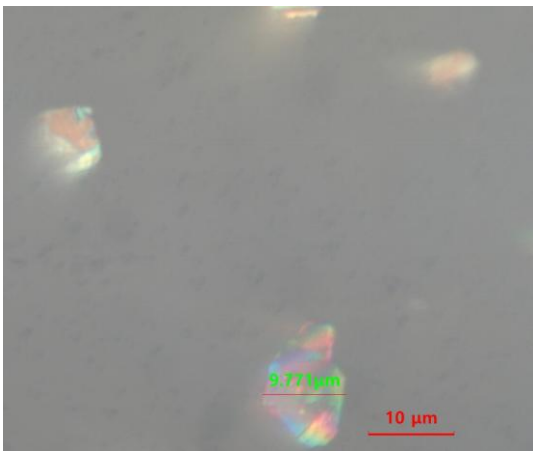
(Mica A)



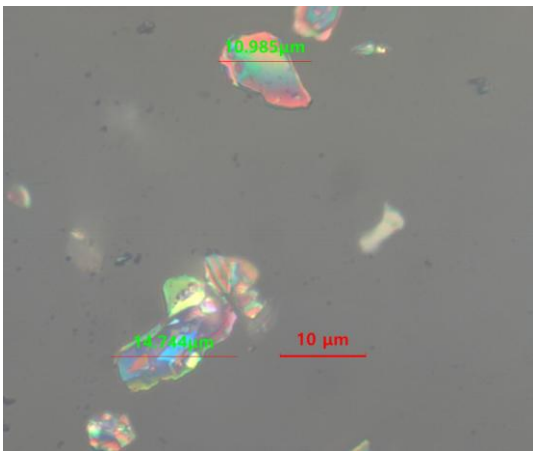
(Mica B)



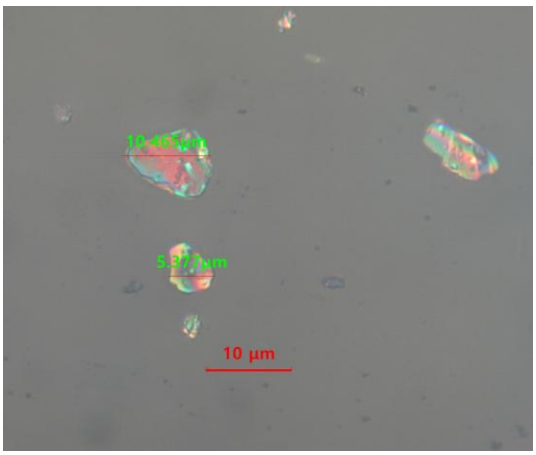
(Sericite A)



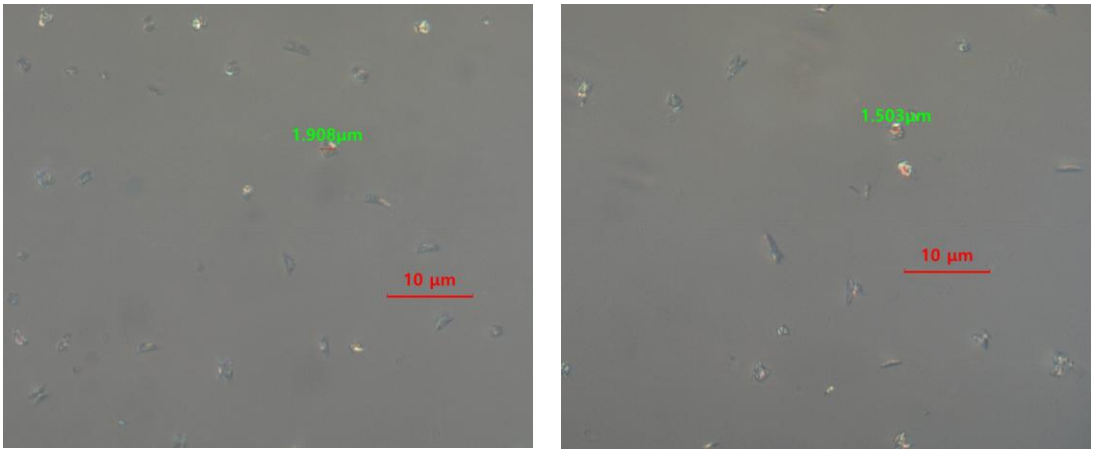
(Sericite B)



(Synthetic fluorphlogopite A)



(Synthetic fluorphlogopite B)



(Kaolin A) (Kaolin B)

Figure 2. Morphology of Samples particles

Talc particles exhibited a platy morphology with moderate thickness. In contrast, mica particles were generally larger, with mica A showing a mixed particle size distribution and mica B displaying a wide, thin platy structure with a high aspect ratio. Sericite A showed particle shapes closely resembling those of talc, with a comparable particle size. Sericite B, however, exhibited a thinner platy shape and larger particles than sample A. For synthetic fluorphlogopite, no significant morphological differences were noted between samples A and B under optical microscopy, although sample A appeared more aggregated and thinner in structure. Kaolin particles displayed a compact morphology with a low aspect ratio, and their particle size was generally smaller compared to the other materials. This distinct structure suggested potential differences in both mechanical and sensory properties when applied in formulations.

3.2. Penetration Depth

Penetration depth was assessed to evaluate compressibility and structural stability of the powder formulations. As all samples were compressed under identical conditions, penetration depth served as a comparative metric reflecting how tightly each formulation was compacted. Even when materials share the same INCI name, differences in particle size and morphology can significantly affect penetration performance. The penetration depth measurement results for the samples are presented in the table below.

Table 3. Sample Penetration Depth Data

Sample	Penetration depth
Talc A sample	1348 (1160, 1490, 1230, 1230, 1330)
Mica A sample	226 (230, 200, 200, 260, 240)
Mica B sample	246 (260, 240, 220, 250, 260)
Sericite A sample	550 (540, 570, 530, 540, 570)
Sericite B sample	Unmeasurable
Synthetic fluorphlogopite A sample	Unmeasurable

Synthetic fluorphlogopite B sample	712 (500,730,540,980,810)
Kaolin A sample	1208 (1110, 2030, 1350, 1550, 1200)
Kaolin B sample	1864 (1820, 1620, 2190, 1330, 2360)

According to the measured data, Kaolin A exhibited the most similar penetration depth value to that of talc, indicating comparable compactness. In contrast, mica samples with large particle sizes showed significantly lower penetration depths, reflecting reduced compressibility. For sericite B and synthetic fluorphlogopite A—both of which exhibited thin platy morphologies—post-compression aging phenomena were observed. In these cases, the central region of the compressed formulations bulged upward over time, suggesting unstable internal packing and inferior compressibility compared to other samples.

3.3. Drop Test

Drop tests were performed to evaluate the mechanical durability of the compressed formulations. Each sample, after being compressed and secured in its aluminum pan, was dropped from a height of 50 cm onto a 1T stainless steel (SUS) plate three times. The residual weight of the formulation remaining in the pan was measured and compared to the initial weight to calculate the retention rate.

Table 4. Sample Drop Test Result

Sample	Initial Weight	Residual rate / Weight after Drop Test
Talc A sample	3.8g	97.7% / 3.71g (3.65g, 3.75g, 3.74g)
Mica A sample	3.6g	90%/ 3.24g (3.23g, 3.31g, 3.19g)
Mica B sample	3.5g	90%/ 3.15g (3.16g, 3.18g, 3.11g)
Sericite A sample	4.3g	92.6%/ 3.98g (4.0g, 3.98g, 3.97g)
Sericite B sample	4.0g	Unmeasurable
Synthetic fluorphlogopite A sample	3.7g	Unmeasurable
Synthetic fluorphlogopite B sample	3.9g	92.3%/ 3.6g (3.6g, 3.6g, 3.6g)
Kaolin A sample	4.0g	90.5%/ 3.62g (3.86g, 3.4g, 3.6g)
Kaolin B sample	4.0g	91.9%/ 3.67g (3.25g, 3.9g, 3.88g)

Talc demonstrated the highest residual rate, indicating superior mechanical integrity and resistance to fragmentation under impact. While most other samples maintained residual rates around 90%, kaolin-based formulations showed inconsistent results. Some retained nearly all material, while others experienced significant breakage. When these outcomes were compared with penetration depth measurements, it was inferred that kaolin's high compressibility renders the formulation more brittle. This brittleness leads to localized failure upon impact, resulting in variable drop stability across samples.

4. Discussion

This study aimed to identify the most promising raw material capable of replacing talc in powder makeup formulations by evaluating various measurement parameters. The morphological characteristics of each powder material were observed using optical microscopy, and particle size was assessed using a particle size analyzer. Based on these characterizations, the raw materials were incorporated into representative formulations, and their applicability was evaluated through penetration depth measurements and drop tests.

Comprehensive analysis of the data revealed that synthetic fluorphlogopite was the most suitable alternative to talc, primarily due to its similar particle size distribution and morphological characteristics. The synthetic fluorphlogopite B sample, in particular, exhibited a d50 value and particle morphology closely matching that of talc. However, when applied to actual formulations, its penetration depth was slightly lower than that of the talc-based formulation, resulting in a softer texture and feel.

From the perspective of penetration depth and mechanical stability, Kaolin A demonstrated the most comparable characteristics to talc. Nonetheless, due to its smaller particle size and brittle nature, formulations containing Kaolin A exhibited higher breakage rates in drop tests, raising concerns about its long-term stability in practical applications.

Given the absence of objective methods to quantify subjective aspects such as formulation sensory properties, synthetic fluorphlogopite B was observed to most closely reproduce the texture and application characteristics of talc, aligning well with our initial hypothesis. These findings support the proposition that raw materials possessing particle size and morphology similar to talc, combined with adequate compressibility to ensure structural stability, can serve as effective alternatives.

Nevertheless, practical application of alternative raw materials may require complementary formulation strategies to mitigate inherent drawbacks. For example, in cases where sericite formulations exhibit low mechanical stability, experienced formulators could leverage its excellent oil absorption properties by adjusting the formulation—such as incorporating additional oil binders or blending with silicate-based powders—to enhance stability. Through such modifications, sericite could also become a viable substitute for talc.

Ultimately, morphological and particle size analysis alone can provide valuable predictive insights into the feasibility of raw materials replacing talc. These findings offer important guidelines for researchers seeking to further develop and optimize powder makeup formulations in line with evolving market demands for clean and sustainable beauty products.

5. Conclusion

In this study, we systematically investigated alternative raw materials to replace talc in powder makeup formulations by evaluating their particle size distribution, morphological characteristics, compressibility, and mechanical stability.

Through comprehensive analysis, it was determined that selecting raw materials with particle size and morphology closely resembling those of talc is the most effective strategy for achieving comparable formulation performance.

Among the tested alternatives, synthetic fluorphlogopite demonstrated the highest potential as a talc substitute. It exhibited a particle size and shape similar to talc, and its formulation performance, particularly in terms of texture and compressibility, closely mirrored that of talc-based formulations. Kaolin also showed promising characteristics with respect to penetration depth; however, its inherent brittleness led to inconsistent mechanical stability upon impact, raising concerns regarding its robustness in real-world applications.

Nevertheless, despite the close physical resemblance of some raw materials to talc, complete substitution remains challenging due to intrinsic differences in mechanical behavior, such as brittleness and aging phenomena observed in compressed powders. These findings underscore the importance of not only matching the particle size and morphology but also optimizing formulation parameters, such as binder type and oil content, to fully compensate for the limitations of alternative materials.

The present study is limited to a comparative evaluation based primarily on particle size, morphology, penetration depth, and drop stability under controlled laboratory conditions. Factors such as long-term stability, environmental resilience (e.g., under humidity or temperature variations), and user sensory evaluations were not extensively explored and warrant further investigation.

Future research should focus on:

- Developing hybrid formulations combining multiple raw materials to achieve a balance between compressibility and mechanical strength.
- Conducting extended stability tests under various environmental conditions to better predict product performance in real-world scenarios.
- Incorporating sensory evaluation protocols to systematically assess user experience, which remains a critical factor for commercial success.

Ultimately, the insights gained from this study provide valuable guidance for the development of talc-free, sustainable powder formulations, aligning with current trends toward clean beauty and regulatory compliance in the global cosmetics industry.

6. Reference

[1] D.L. Longo, R.C. Young, COSMETIC TALC AND OVARIAN CANCER, The Lancet, Volume 314, Issue 8138, 1979, Pages 349-351, ISSN 0140-6736

[2] Nicolas Wentzensen, Katie M. O'Brien, Talc, body powder, and ovarian cancer: A summary of the epidemiologic evidence, Gynecologic Oncology, Volume 163, Issue 1, 2021, Pages 199-208, ISSN 0090-8258