Understanding the Effect of Biocidal Agents on Leather Disintegration

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Abstract

This study investigates the impact of biocidal agents on the disintegration of leather, focusing on chromium-free leathers that are compostable.

The leather industry faces increasing pressure to produce sustainable materials, particularly in the context of the Circular Economy Action Plan and the EU's End-of-Life Directive. This study explores how biocidal agents affect the disintegration of leather in composting environments, using the ISO 20200:2023 disintegration test.

Seven leather samples were tested by ISO 20200:2023. The samples included untreated leather and leathers treated with three different biocides at standard and high concentrations. The biocides used were 4-chloro-3-methylphenol (CMK), 2-phenylphenol (OPP), and 2-octyl-1,2-thiazol-3-one (OIT). The tests were conducted over 84 days in thermophilic conditions, followed by an additional 84 days in mesophilic conditions. The untreated control leather disintegrated quickly. Biocide-treated leathers, at both standard and high concentrations, showed delayed disintegration.

Biocides play a crucial role in protecting leather from microbial growth during its production and storage life. However, they can still be present in the final leather article at its End-of-Life. One might expect that the presence of biocides, especially at very high concentrations, would result in non-compostable material due to the inhibitory effects of biocides on microorganisms, which are essential for composting.

This study has shown that all leathers protected with biocides in their working life, can biodegrade in a reasonable time-frame in a natural environment like compost. Leathers continue to break down even at 10 times normal application concentrations.

1 Introduction

The global leather industry stands at a critical juncture, where traditional manufacturing practices are increasingly being scrutinized under the lens of environmental sustainability and circular economy principles. As leather is derived from animal hides—a byproduct of the meat industry—it inherently aligns with the concept of biomass valorization. However, the environmental impact of leather products at their end-of-life stage remains a subject of growing concern, particularly in light of the European Union's Circular Economy Action Plan and the End-of-Life Vehicle (ELV) Directive, which demand higher rates of material recovery and recycling (Wang et al. 2024).

Biodegradability has emerged as a key indicator for evaluating the ecological performance of leather. It refers to the microbial-mediated breakdown of organic matter into simpler compounds, a process that is essential for materials intended for organic recycling pathways such as composting (Wang et al. 2024). Natural leather, primarily composed of collagen, is generally more biodegradable than synthetic alternatives like polyurethane (PU) or microfiber-based materials (Wang et al. 2024). However, the tanning process—designed to enhance leather's durability, thermal stability, and resistance to microbial attack—can significantly alter its biodegradation profile. In particular, chrome tanning, the most widely used method, has been associated with reduced biodegradability and environmental (Wang et al. 2024).

In response, the industry has seen a surge in the development of chrome-free tanning technologies, including aldehyde-based, vegetable-based, and synthetic-organic hybrid systems (Wang et al. 2024). These alternatives aim to strike a balance between performance and environmental compatibility. Yet, another critical factor influencing leather's end-of-life behavior is the use of biocidal agents. These substances are indispensable during production and storage to prevent microbial spoilage, but their residual presence in finished leather may inhibit microbial activity during composting, potentially delaying or impeding disintegration.

Despite the increasing relevance of compostability as a sustainability metric, standardized methodologies for assessing leather disintegration under composting conditions—such as ISO 20200:2023—are still being adapted and validated for industrial application (Boavida et al. 2025). Moreover, the distinction between physical disintegration and true biodegradation is often blurred, although both are essential for certifying a material as compostable under standards like EN 13432:2000 or ISO 17088:2021 (Boavida et al. 2025).

This study contributes to the growing body of research on sustainable leather production by exploring the interplay between biocide application and compostability. It seeks to clarify whether the protective benefits of biocides during a leather product's service life come at the cost of its environmental degradability, and how this trade-off can be managed through informed material design and testing.

2 Material and Methods

2.1 Leather intermediates (Wet White)

The experimental leather samples were produced at the pilot tannery of the FILK Institute in Freiberg, Germany. The process focused on the preparation of wet white leather, tanned using glutaraldehyde, a chromium-free tanning agent known for its potential biodegradability.

Fresh bovine hides were used as the raw material. After standard soaking, liming, and unhairing procedures, the pelts were delimed and bated to prepare them for tanning. The tanning process was carried out using glutaraldehyde as the sole tanning agent, following a standardized wet white recipe.

The wet white leathers were treated with three different biocidal agents, each applied at two concentration levels (Table 1) based on pelt weight:

- 4-chloro-3-methylphenol (CMK), CAS No. 59-50-7
- 2-phenylphenol (OPP), CAS No. 90-43-7
- 2-octyl-1,2-thiazol-3-one (OIT), CAS No. 26530-20-1

Table 1: Biocide Dosage overview

Active ingredient	Standard Dose (mg/kg pelt weight)	High Dose (mg/kg pelt weight)
OPP	1485	14850
CMK	1400	14000
OIT	392	3920

The high-dose treatments represent approximately ten times the typical industrial application rate for single-agent use. In commercial practice, biocides are often applied in combinations to preserve semi-finished leather intermediates during storage and transport. To simulate a worst-case scenario for compostability, the biocides in this study were applied individually at elevated concentrations.

In addition to the biocide-treated samples, a control leather was produced without any biocidal treatment. This sample served as a reference to assess the natural disintegration behavior of glutaraldehyde-tanned leather under composting conditions.

All samples were labeled and stored under controlled conditions prior to further testing.

2.2 Analytical determination of biocidal active ingredients

The procedure was carried out in alignment with the principles of ISO 13365, which outlines methods for the determination of specific chemical substances in leather using chromatographic techniques.

Leather samples are cut into small pieces. A portion of 2.5 g is weighed into a 100 mL graduated flask.

The sample is extracted with an appropriate solvent in an ultrasonic bath. The supernatant is then filtered. This extraction step is repeated once under the same conditions.

An aliquot of 1 mL from the extract is transferred into a centrifuge tube and centrifuged. The clear supernatant is transferred into an HPLC vial.

The analysis is performed using HPLC with a C18 column and using UV detection at compound-specific wavelengths.

2.3 ISO 20200:2023

The disintegration behavior of the tested materials under composting conditions was assessed in accordance with the international standard ISO 20200:2023. This method specifies a laboratory-scale procedure for determining the degree of physical disintegration of plastic materials when subjected to controlled aerobic composting conditions.

The testing was carried out by Authenticae Ltd. (UK), following the procedural guidelines outlined in the standard. Samples were exposed to a simulated composting environment under defined temperature, humidity, and aeration conditions. The extent of disintegration was monitored over time by visual inspection and mass loss, in line with the standard's criteria.

All experimental conditions, including compost composition, incubation parameters, and evaluation intervals, were maintained as prescribed by ISO 20200:2023 to ensure reproducibility and comparability of results.

The disintegration tests were conducted in triplicate for each sample over a period of 84 days under thermophilic composting conditions, as prescribed by ISO 20200:2023. Following this phase, the test was extended by an additional 84 days under mesophilic conditions at 25 °C, in accordance with the standard's provisions for extended observation.

A soil inoculum was added to initiate microbial activity, and the composting environment was maintained under controlled temperature and humidity conditions. The compost was monitored for microbial activity and physical changes in the test materials.

The disintegration was assessed through, visual inspection and photographic documentation at regular intervals, Mass loss measurements, Observation of mycelial growth and fragmentation patterns.

The degree of disintegration was recorded at the end of both the thermophilic and mesophilic phases, providing a total observation period of 168 days.

3 Results and Discussion

3.1 Analytical determination of biocidal active ingredients

In this study, leather samples were treated with three different biocidal agents—CMK, OPP and OIT—each applied at two concentration levels: Standard and High. For each treatment, the theoretical biocide content was calculated based on the dosage. The actual biocide content in the leather was then analytically determined, both in its original state and adjusted for a standardized moisture content (Table 2).

Table 2: Biocide Content in Leather Samples, ND = not detectable

Active Ingredient	Theoretical Offer (mg/kg)	Biocide Content as is (mg/kg)	Biocide Content Corrected to 50% Water (mg/kg)
OPP (standard)	1485	1490	2025
OPP (high)	14850	14660	18510
CMK (standard)	1400	880	1100
CMK (high)	14000	11070	13780
OIT (standard)	392	575	725
OIT (high)	3920	4058	5375
Control w/o biocide	0	ND	ND

3.2 Results ISO 20200:2023

The disintegration of leather samples was evaluated over two consecutive 84-day periods under thermophilic and mesophilic composting conditions, respectively. The percentage of disintegration was determined for each treatment group. According to ISO 20200, successful disintegration of a test material under controlled composting conditions is achieved when no more than 10% of the original dry mass remains after 84 days of composting. The results are summarized in Table 3

Table 3: ISO 20200 Thermophilic and mesophilic results after 84 respectively 168 days. The values in parentheses represent the standard deviation of the disintegration percentages, based on triplicate testing.

Treatment	Disintegration (%) Thermophilic (84 days)	Disintegration (%) Mesophilic (84 days)
Control (no treatment)	100.00	100.00
CMK (Standard)	65.34 ± 12.80	70.02 ± 8.32
CMK (High)	63.79 ± 12.01	67.80 ± 12.45
OIT (Standard)	100.00	100.00
OIT (High)	100.00	100.00
OPP (Standard)	75.17 ± 10.18	88.44 ± 0.60
OPP (High)	57.75 ± 14.41	59.57 ± 18.59

Control (Untreated Leather): The glutaraldehyde-tanned, untreated control sample demonstrated rapid disintegration, breaking down completely within 35 days.

OPP-Treated Leather: Leathers treated with OPP showed incomplete disintegration. While many fragments had broken down, approximately 12% of the mass remained as larger, more intact pieces. The higher concentration of OPP correlated with an increased presence of these larger, less-degraded fragments.

CMK-Treated Leather: The distribution of small fragments and larger pieces was similar to that of the OPP-treated samples, but the larger fragments were more prominent.

OIT-Treated Leather: Both standard and high-dose OIT-treated samples were quickly overwhelmed by the compost's microbial activity. The degradation of the intermediates was fast.

Photographic documentation confirmed progressive fragmentation and mycelial growth on all samples (Figure 1-7). Visual observations were recorded at multiple time points (Days 9, 20, 35, 49, 63, 84, 126, and 168), with all samples showing signs of microbial colonization by day 20.

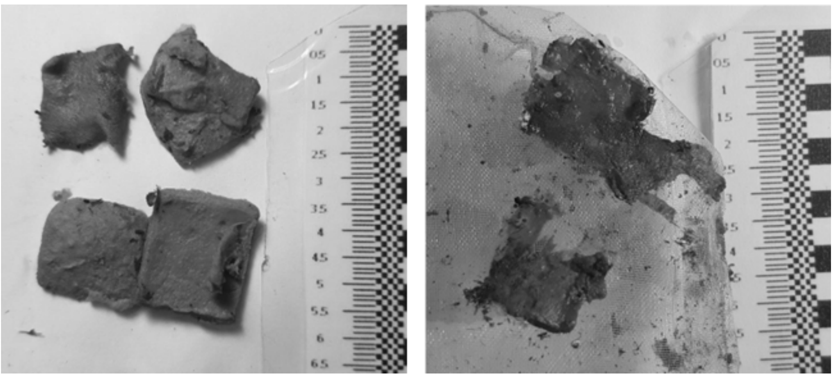

Figure 1: Control sample: Visual observations from left to right after day 9, 20, 35, 49, 63, 84, 126, and 168; If there are no pictures, then no fragments of the leather could be found on these days.

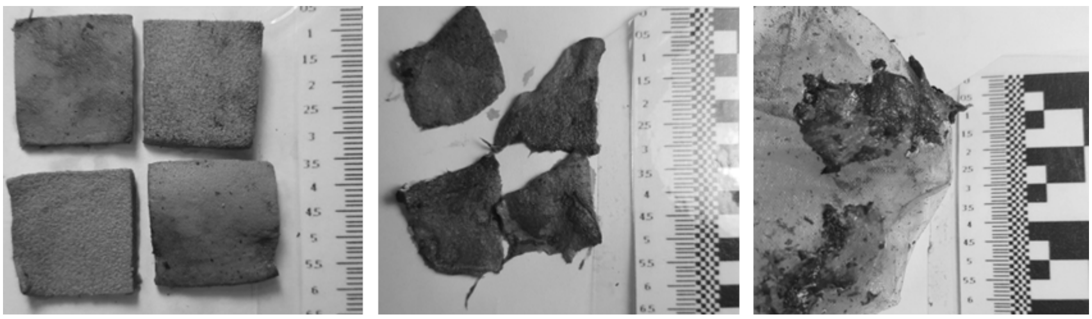

Figure 2: OIT standard samples: Visual observations from left to right after day 9, 20, 35, 49, 63, 84, 126, and 188; If there are no pictures, then no fragments of the leather could be found on these days.

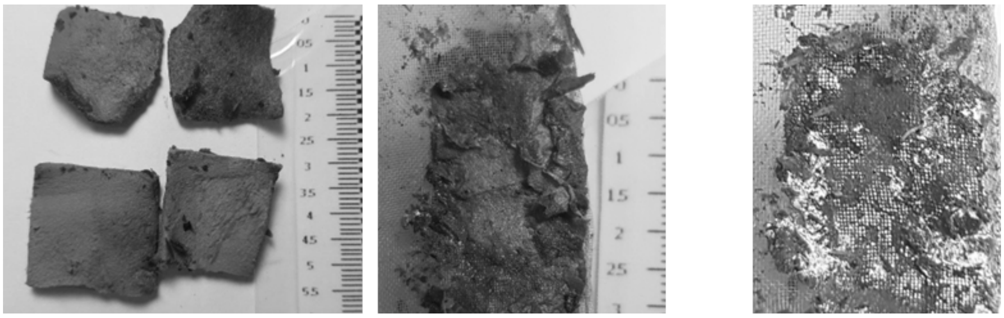

Figure 3: OIT high samples: Visual observations from left to right after day 9, 20, 35, 49, 63, 84, 126, and 168; If there are no pictures, then no fragments of the leather could be found on these days.

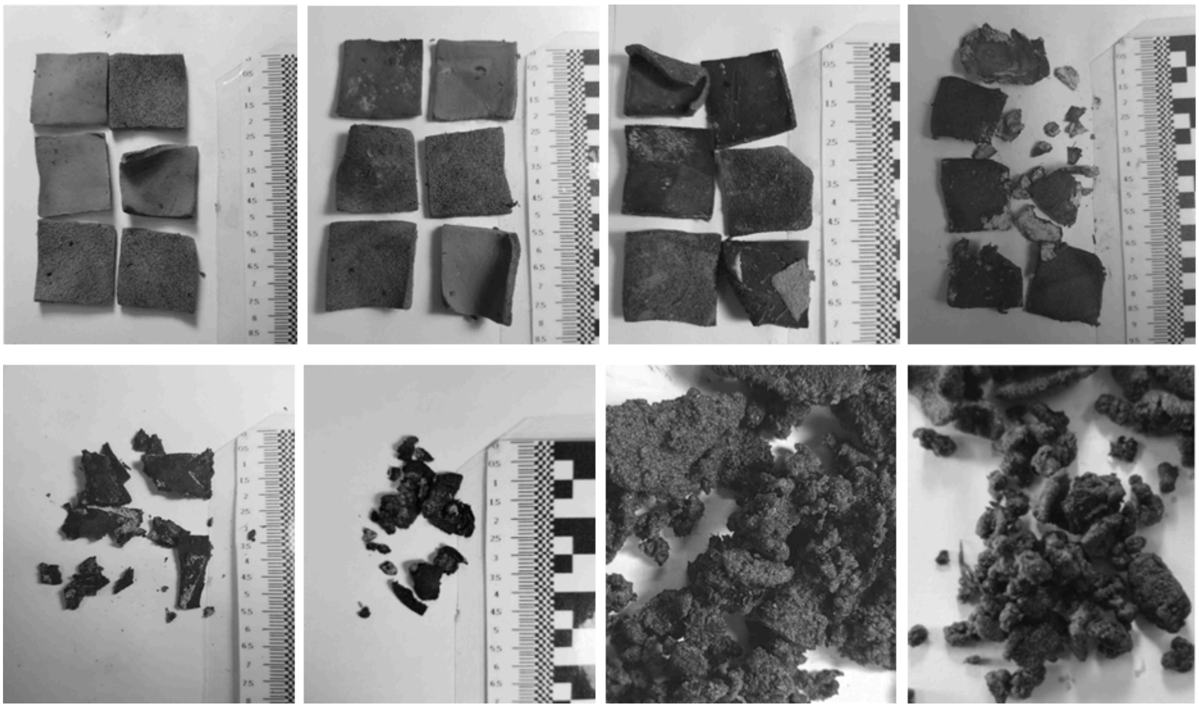

Figure 4: OPP standard samples: Visual observations from left to right after day 9, 20, 35, 49, 63, 84, 126, and 168; If there are no pictures, then no fragments of the leather could be found on these days.

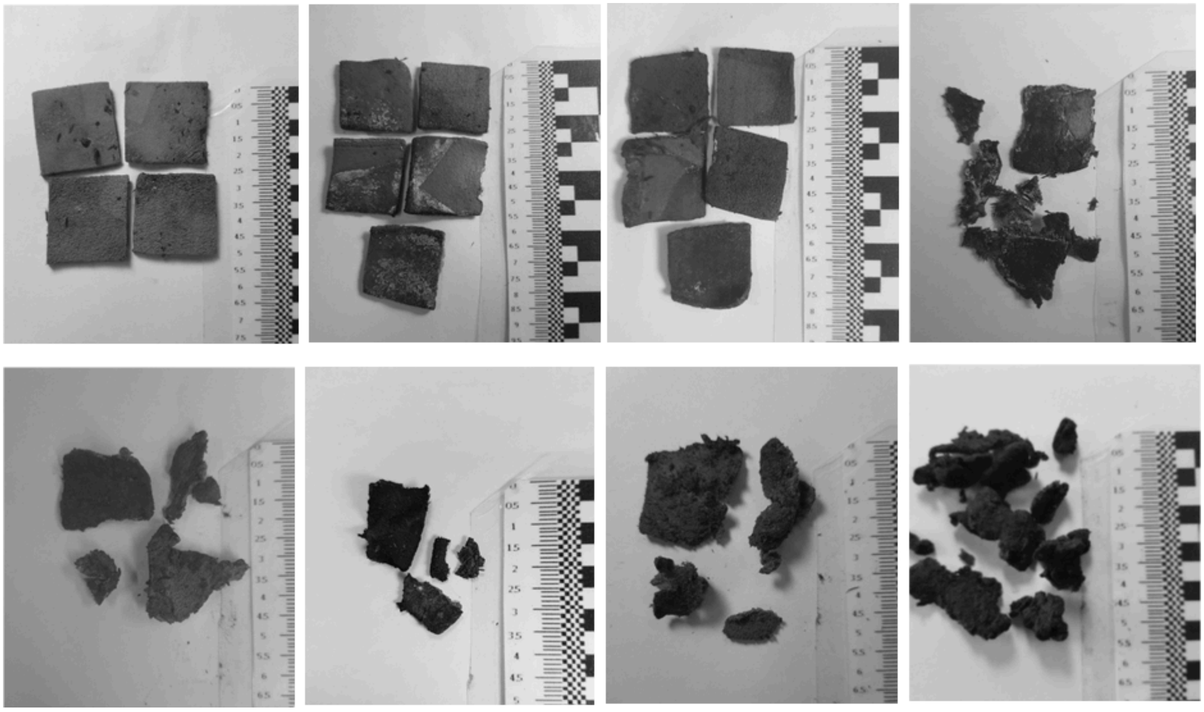

Figure 5: OPP high samples: Visual observations from left to right after day 9, 20, 35, 49, 63, 84, 126, and 168; If there are no pictures, then no fragments of the leather could be found on these days.

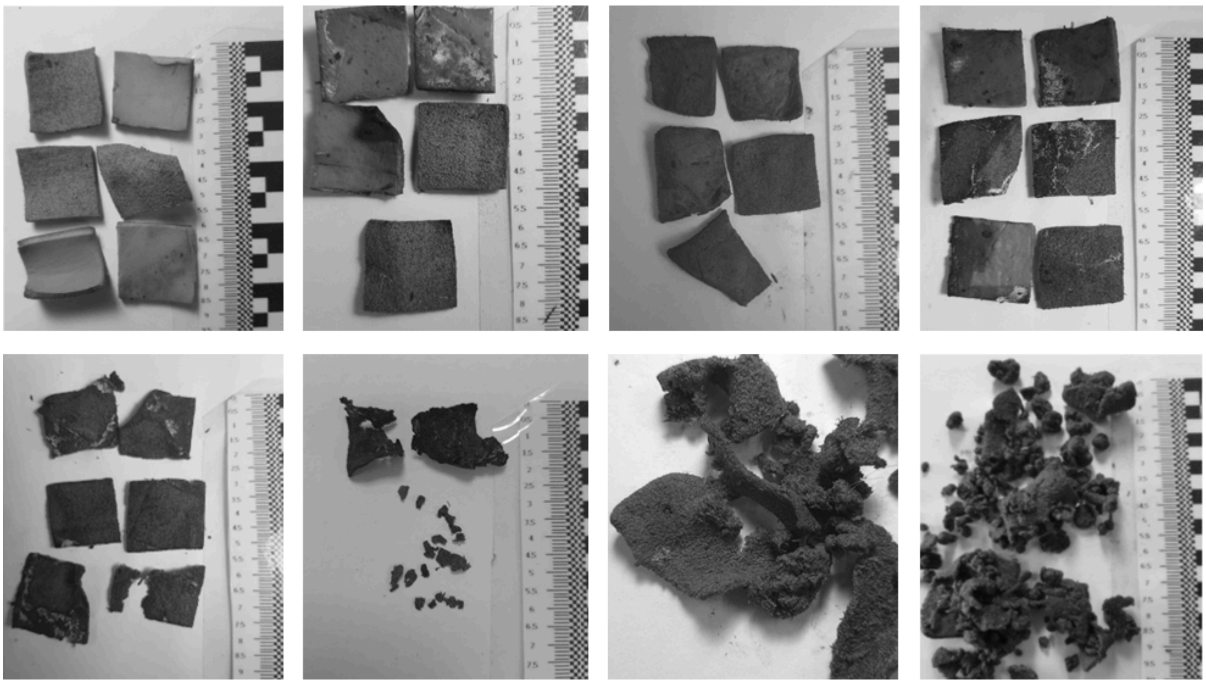

Figure 6: CMK standard samples: Visual observations from left to right after day 9, 20, 35, 49, 63, 84, 126, and 168; If there are no pictures, then no fragments of the leather could be found on these days.

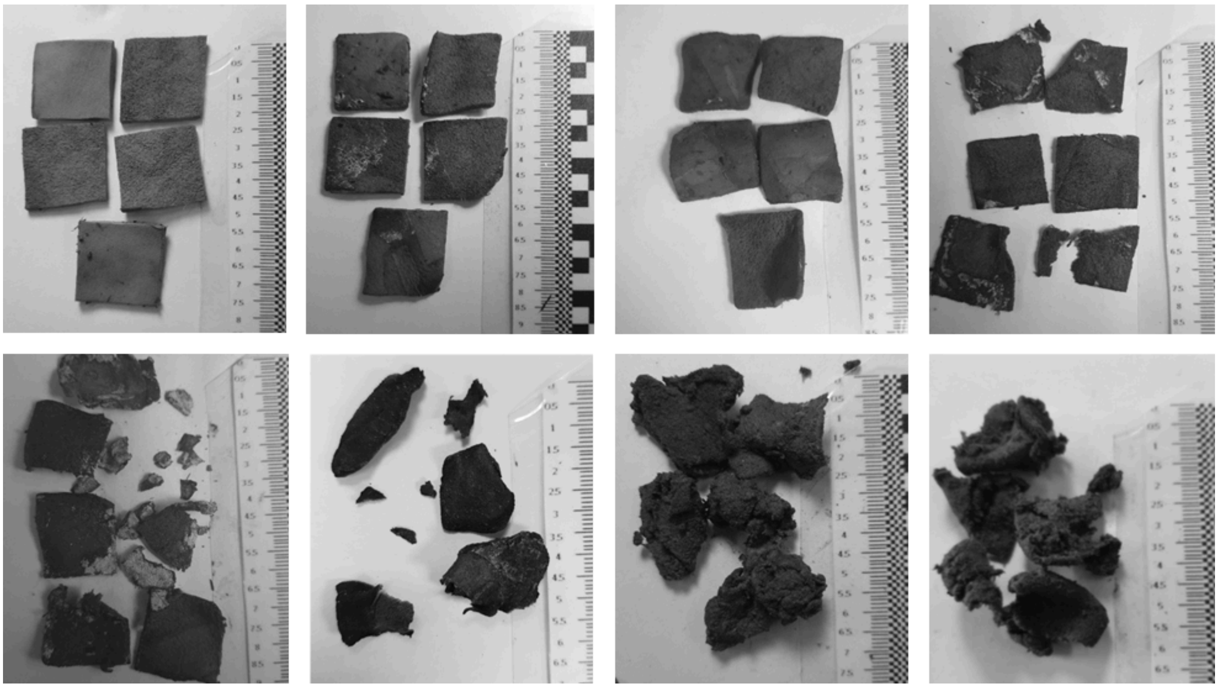

Figure 7: CMK high samples: Visual observations from left to right after day 9, 20, 35, 49, 63, 84, 126, and 168; If there are no pictures, then no fragments of the leather could be found on these days.

4 Discussion

The results of the disintegration study conducted under ISO 20200:2023 conditions confirm that leather materials treated with biocidal active ingredients are capable of undergoing substantial or complete disintegration in composting environments. All tested substances—CMK, OPP, and OIT—allowed for progressive breakdown of the leather samples, even when applied at concentrations ten times higher than standard industrial levels.

The study demonstrates that these protective functions do not compromise the material's ability to disintegrate at the end of its life cycle. Notably, even at concentrations ten times higher than standard application levels, none of the tested biocides prevented the eventual disintegration of the leather substrates. This confirms that the antimicrobial efficacy of these agents does not equate to long-term environmental persistence in composting environments. This compatibility is a key requirement for modern leather production, especially in light of increasing regulatory and sustainability demands.

The results highlight the varying efficacy of different biocides in delaying leather disintegration. OIT, an electrophilically surface-active biocide, was quickly neutralized, allowing for rapid degradation of the leather intermediate. This suggests that OIT may be more effective for short-term preservation but is less suitable for applications where long-term resistance to microbial attack is required.

In contrast, OPP and CMK, both membrane-active biocides, demonstrated greater stability and a more prolonged protective effect. These biocides are widely used for long-term preservation of leather intermediates, such as wet blue and wet white, due to their ability to maintain material integrity over extended periods. However, even these more robust biocides did not prevent disintegration, as evidenced by the widespread mycelial growth and the breakdown of the leather samples. The persistence of these biocides in the leather matrix likely delays the onset of biodegradation but does not halt it entirely.

In summary, the results affirm that biocidal active ingredients are not only indispensable for high-quality leather manufacturing, but also compatible with environmental goals related to compostability and material circularity. Their use enables the leather industry to meet both performance and sustainability criteria, supporting the development of advanced, bio-circular leather products.

5 Conclusion

This study provides compelling evidence that biocidal active ingredients, when used in the preservation of intermediate leather materials, are fully compatible with the principles of compostability and end-of-life disintegration. Under ISO 20200:2023 conditions, even at elevated concentrations, biocides such as CMK, OPP, and OIT did not hinder the breakdown of leather in composting environments.

These findings are highly encouraging, as they demonstrate that biocidal agents can deliver effective microbial protection during the leather's service life while still allowing for natural degradation at the end of life. The ability to combine robust preservation with reliable disintegration supports the development of leather products that meet both technical performance and environmental sustainability goals.

In conclusion, biocidal technologies play a vital role in modern leather manufacturing. They enable the production of durable, hygienic materials that align with circular economy principles by ensuring that leather can safely and effectively return to the environment through composting.

6 References

Boavida et al. (2025)	Evaluation of the Disintegration of Bioplastics and Rabbit Leather, Springer 2025
Burdi et al. (2024)	Modelling Leather Industry Waste from the Circular Economy, Springer 2024
Wang et al. (2024)	Springer, Biodegradability of Leather: A Crucial Indicator, Springer 2024